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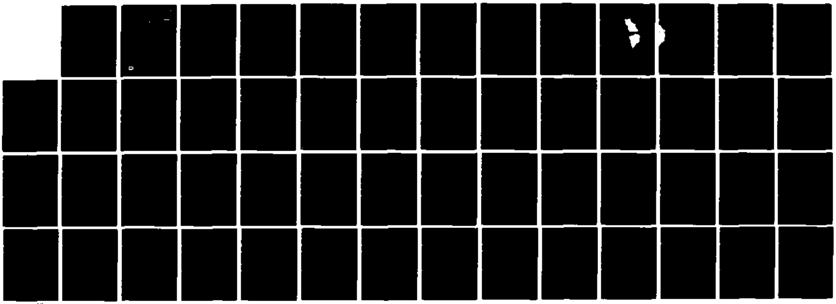

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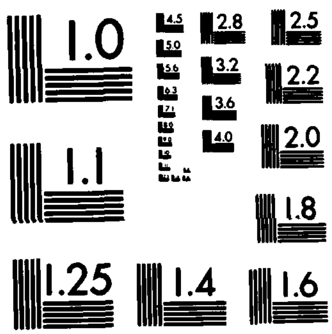

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Pawcatuck River and Narragansett Bay
Drainage Basins

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Pawcatuck and Woonasquatucket River Basins and Narragansett Bay Local Drainage Area

US Army Corps of Engineers
New England Division

UNCLASSIFIED

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"Pawcatuck River and Narragansett Bay Drainage Basins" study.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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Flood forecasting
River basins
Floods
Channel improvement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Potential flood control measures and associated water resources problems in the Woonasquatucket and Pawcatuck River Basins and Narragansett Bay Local Drainage area were studied as part of the Pawcatuck River and Narragansett Bay Drainage Basins (PNB) study. In the Pawcatuck River, major flooding has not occurred and can be prevented through preservation of the major wetland areas. The COE recommends that no action plan for the subject study areas. This means that nothing more will be done by the Corps of Engineers and it is assumed that local communities will participate in the National Flood Insurance Program (NFIP)

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and enforce its requirements to control the future growth within flood plains.

PAWCATUCK AND WOONASQUATUCKET RIVER BASINS AND NARRAGANSETT BAY LOCAL DRAINAGE AREA

MAIN REPORT

OCTOBER 1981

New England Division
U.S. Army Corps of Engineers
Waltham, Massachusetts 02254

EXECUTIVE SUMMARY

Potential flood contol measures and associated water resource problems in the Woonasquatucket and Pawcatuck River Basins and Narragansett Bay Local Drainage area were studied as part of the Pawcatuck River and Narragansett Bay Drainage Basins (PNB) Study. The appropriate flood control measures for the remainder of the river basins included in the authorizing resolution have been considered in separate feasibility studies.

These three study areas were combined into one report when it became evident that no structural plans would be recommended in any of these three areas. By combining these areas into one report, duplication of work was prevented as background information, plan formulation process and public views were similar in each of these study areas.

On the Pawcatuck River, major flooding has not occurred and can be prevented through preservation of the major wetland areas, particularly in the lower portion of the basin. Several channel improvement plans were considered for the Woonasquatucket, Moshassuck and West Rivers. These would provide flood protection from a 100-year to a Standard Project Flood event, however all of these were impractical from an economic or engineering point of view.

The No Action Plan and applicable regulatory measures are recommended for the subject study areas. All other flood control measures investigated for these areas are not considered feasible. In the No Action Plan nothing more will be done by the Corps of Engineers. It is assumed that local communities will participate in the National Flood Insurance Program (NFIP) and enforce its requirements to control the future growth within the flood plains. Regulatory measures do not reduce flooding but do discourage the use and development of the flood plains, lessening the threat of future flood damage. The NFIP and flood plain regulation such as zoning, subdivision regulations and building and housing codes are recommended. Flood warning systems, urban renewal, tax incentives, and public open space acquisition will also help limit future flood damages.

PAWCATUCK AND WOONASQUATUCKET
RIVER BASINS AND NARRAGANSETT BAY
LOCAL DRAINAGE AREA

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CHAPTER ONE: INTRODUCTION

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INTRODUCTION

The purpose of this study is to investigate the flooding and associated water resource problems in the Pawcatuck and Woonasquatucket River Basin and Narragansett Bay local drainage area and to develop a plan, acceptable to the local interests, that would solve these problems. Various flood control alternatives responsive to the needs of the basin are presented in this report.

STUDY AUTHORITY

This report is submitted in partial compliance with seven Congressional resolutions, combined under one resolve adopted by the Committee on Public Works of the United States Senate. These resolutions submitted after the March 1968 flood, authorized the Pawcatuck River and Narragansett Bay Drainage Basins (PNB) Study, which includes the Pawcatuck, Woonasquatucket and Narragansett Bay local drainage areas.

SCOPE OF THE STUDY

This report presents the results of a study of the flooding and water resources problems in the Pawcatuck, Woonasquatucket and Narragansett Bay local drainage areas, three of five major watersheds in the Pawcatuck River and Narragansett Bay Drainage Basins (PNB) Study. It makes a determination of the advisability of making improvements in the interest of flood control and allied purposes. A map showing the relationship of the study areas to the entire PNB study area follows as Plate 1. All reasonable alternative plans to solve the area's water resource problems were considered. The selection of the recommended plan was made after considering all factors, including those expressed by concerned agencies and local interests. The studies were made in the depth and detail needed to permit plan selection and to determine its feasibility.

The remainder of the river basins included in the authorizing resolutions have been considered in separate feasibility studies. See Appendix 1 for listing of reports.

STUDY PARTICIPANTS AND COORDINATION

The New England Division, Corps of Engineers, had the principal responsibility for conducting and coordinating the study and the plan formulation, consolidating information from the studies by other agencies, and preparing this report. Other participants contacted during the progress of the study and their views incorporated, included the following:

Federal Agencies

US Fish and Wildlife Service

US Environmental Protection Agency

New England River Basins Commission

State Agencies

Rhode Island Water Resources Board

Statewide Planning Program

Department of Public Health

Department of Environmental Management

Historical Preservation Commission

Four initial public meetings were held in May 1969 for the PNB study. These meetings were held in Taunton and Uxbridge, Massachusetts and Providence and Kingston, Rhode Island. The purposes of these meetings were to afford local interests the opportunity to express their needs and desires, to exchange information concerning the study, and to comment on some of the possible plans that could be considered.

PRIOR STUDIES

Numerous reports have been prepared focusing attention on the Pawcatuck and Woonasquatucket River Basin and Narragansett Bay local drainage area. Some of the more pertinent are listed below:

Early Rhode Island Water Supply Reports, 1928-1936

Flood Control Survey Report of 1939

The New England-New York Interagency Committee Report, March 1955

Fox Point Barrier Report

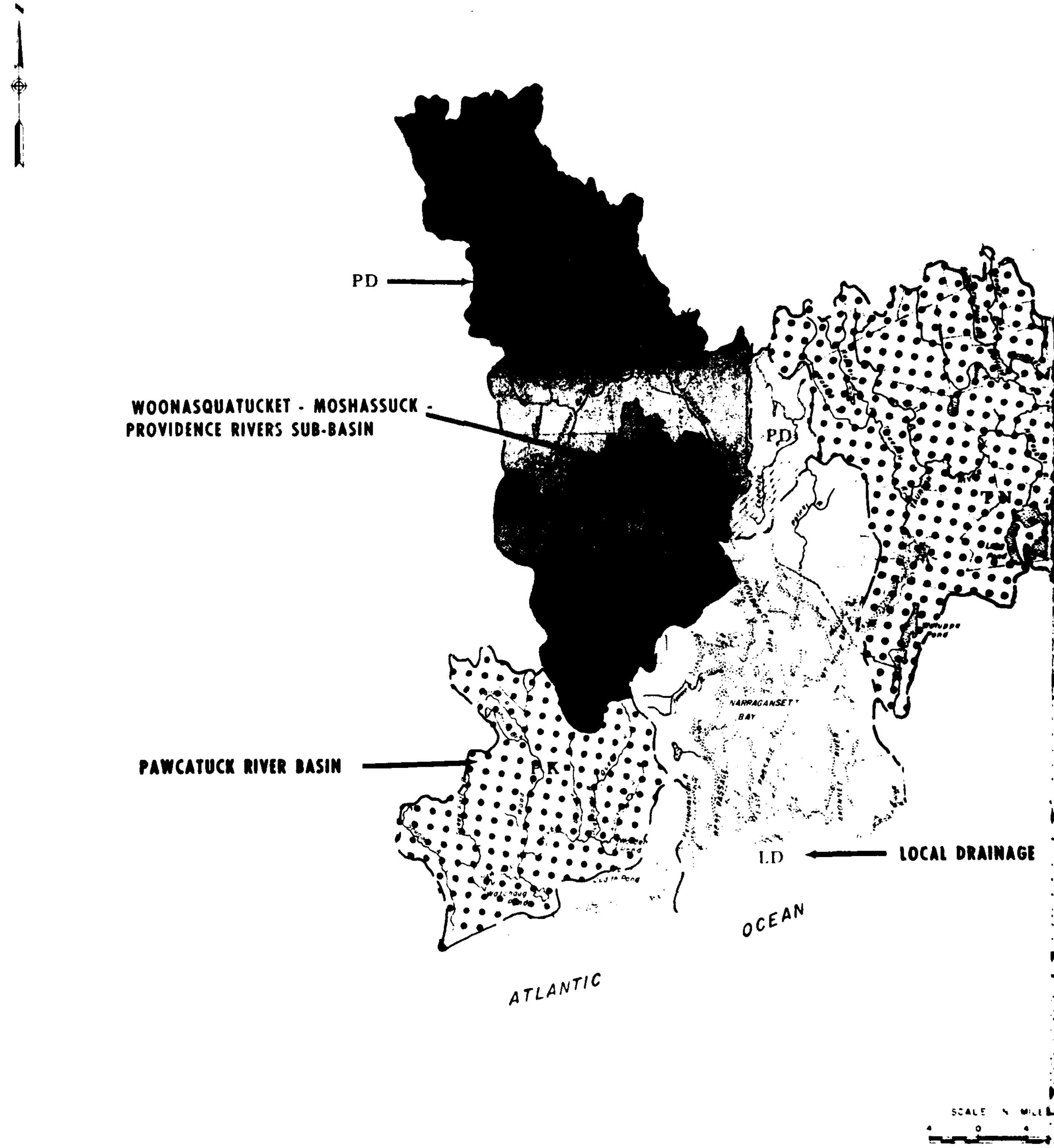
Corps of Engineers Navigation Survey Reports

Narragansett Bay Area Hurricane Survey Reports, August 1957

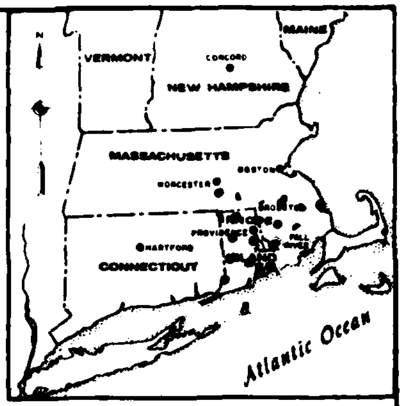
Hurricane Protection Project, Pawcatuck, Connecticut

Rhode Island Water Supply Reports, June 1967

Northeastern United States Water Supply Study Feasibility Report, November 1969



PD
WOONASQUATUCKET - MOSHASSUCK -
PROVIDENCE RIVERS SUB-BASIN
PD
PAWCATUCK RIVER BASIN
PK
NARRAGANSETT
BAY
LD
LOCAL DRAINAGE
OCEAN
ATLANTIC



LOCATION MAP

SCALE IN MILES

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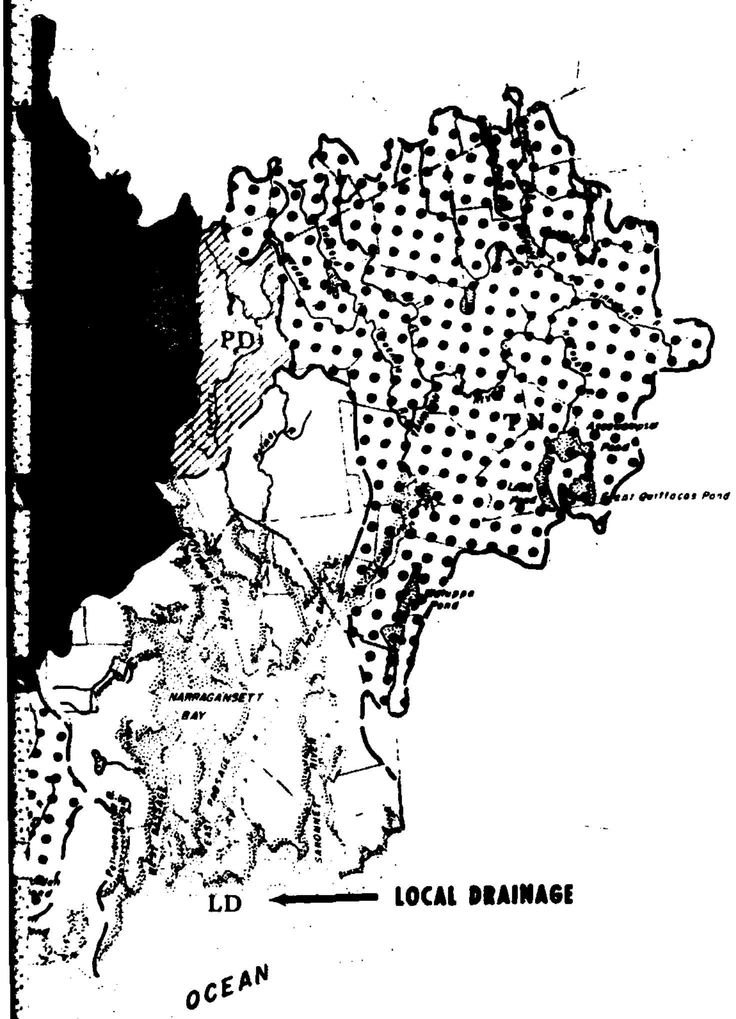


SCALE IN MILES

LEGEND

———	COMMUNITY BOUNDARY
— — —	COUNTY BOUNDARY
— - —	STATE LINE
( )	RESPECTIVE BASIN LIMITS
PX	PAWTUXET RIVER BASIN
TN	TAUNTON RIVER BASIN
PK	PAWCATUCK RIVER BASIN
LD	LOCAL DRAINAGE
PD	PROVIDENCE RIVER GROUP WATERSHED
PD_1	WOONASQUATUCKET - MOSHASSUCK - PROVIDENCE RIVERS SUB-BASIN
PD_2	BLACKSTONE RIVER SUB-BASIN
PD_3	TENMILE - SEEKONK RIVERS SUB-BASIN

WATER RESOURCES MANAGEMENT REPORT

PAWCATUCK RIVER AND NARRAGANSETT BAY STUDY

BASIN MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS

PLATE 1

Flood Control Reconnaissance Report, December 1971

North Atlantic Regional Water Resources Study Report, June 1972

Southeastern New England Study, March 1976

Flood Insurance Studies under the authority of the National Flood Insurance Act of 1968 have been completed for most of the towns and cities in the study area.

Other PNB reports completed are:

Assessment of the Flood Problems of the Taunton River Basin in Massachusetts, 1979

PNB Water Supply Study, January 1979

Big River Reservoir Project, July 1981

Blackstone River Watershed, 1981

CHAPTER TWO: PROBLEM IDENTIFICATION

PLATES

PROBLEM IDENTIFICATION

NATIONAL OBJECTIVES

These objectives are directed towards National, State, and local water and related land resource management needs specific to a given study area that can be addressed to enhance multiple objectives of National Economic Development (NED) and Environmental Quality (EQ).

Components of the NED objective for the Pawcatuck and Woonasquatucket River Basin and Narragansett Bay local drainage area are:

1. Reduce flood damages along the rivers and coastal areas of the study area.

2. Opportunities for additional water supply to the State of Rhode Island.

3. Improve the economy of the underemployed labor force.

Components of the EQ objective for this study area are:

1. Prevent further water quality degradation of the area's rivers.

2. Create recreational areas to satisfy local demand for noncontact uses.

3. Develop a management plan precluding unwise use of the flood plains.

EXISTING CONDITIONS

The Pawcatuck River Basin, a drainage area of 303 square miles, lies in southwestern Rhode Island and southeastern Connecticut. The Pawcatuck River, rising in Worden Pond in South Kingston, flows 33 miles through a multitude of lakes and swamps to Little Narragansett Bay (see Plate 2). The principal tributaries of the Pawcatuck River are the Usquebaug, Beaver, Wood, Ashaway and Shunook Rivers. Inland wetlands totaling over 47 square miles constitute over 15 percent of the total basin area. The largest individual wetland area in the basin is the Great Swamp located within the Great Swamp Wildlife Reservation in South Kingstown.

The average daily discharge for 36 years of record is 563 cubic feet per second (cfs) at the Westerly, Rhode Island gage which has a drainage area of 295 square miles. The largest flow recorded at Westerly was 4,470 cfs on 18 March 1968.

The Woonasquatucket River Basin lies entirely within the north-northwestern portion of Rhode Island. Draining an area of 75.2 square miles, it flows into the Providence River approximately 0.2 mile north of the Fox Point Hurricane Barrier in Providence (see Plate 3). The

waterways of the basin were originally developed for textile manufacturing; several dams and impoundments still remain. The Woonasquatucket River is about 19 miles in length and its tributary the Moshassuck River is 9.5 miles. The major tributary of the Moshassuck is the West River.

The average daily flow in the Woonasquatucket River at Centerdale, Rhode Island is 71.3 cfs for 36 years of records. The maximum flow recorded at Centerdale, 1440 cfs, occurred March 18, 1968. The average daily flow for the Moshassuck at Providence is 39.7 cfs and the maximum 2390 cfs (18 March 1968).

Narragansett Bay is located in the eastern portion of Rhode Island. The Bay area consists of the system of interconnected waterways that discharge into the Atlantic Ocean off the south shore of Rhode Island between Point Judith on the west and Sakonnet Point on the east (see Plate 4). The total Narragansett Bay drainage area is about 1870 square miles. The major tributaries to Narragansett Bay are the Pawtuxet, Woonasquatucket, Moshassuck, Blackstone, Ten-Mile and Taunton Rivers. The shoreline of the bay is comprised of many harbors, bays and coves; several of these are used for mooring a great number of commercial and recreational boats. The beautiful sandy beaches along the coastline are used extensively for recreational purposes.

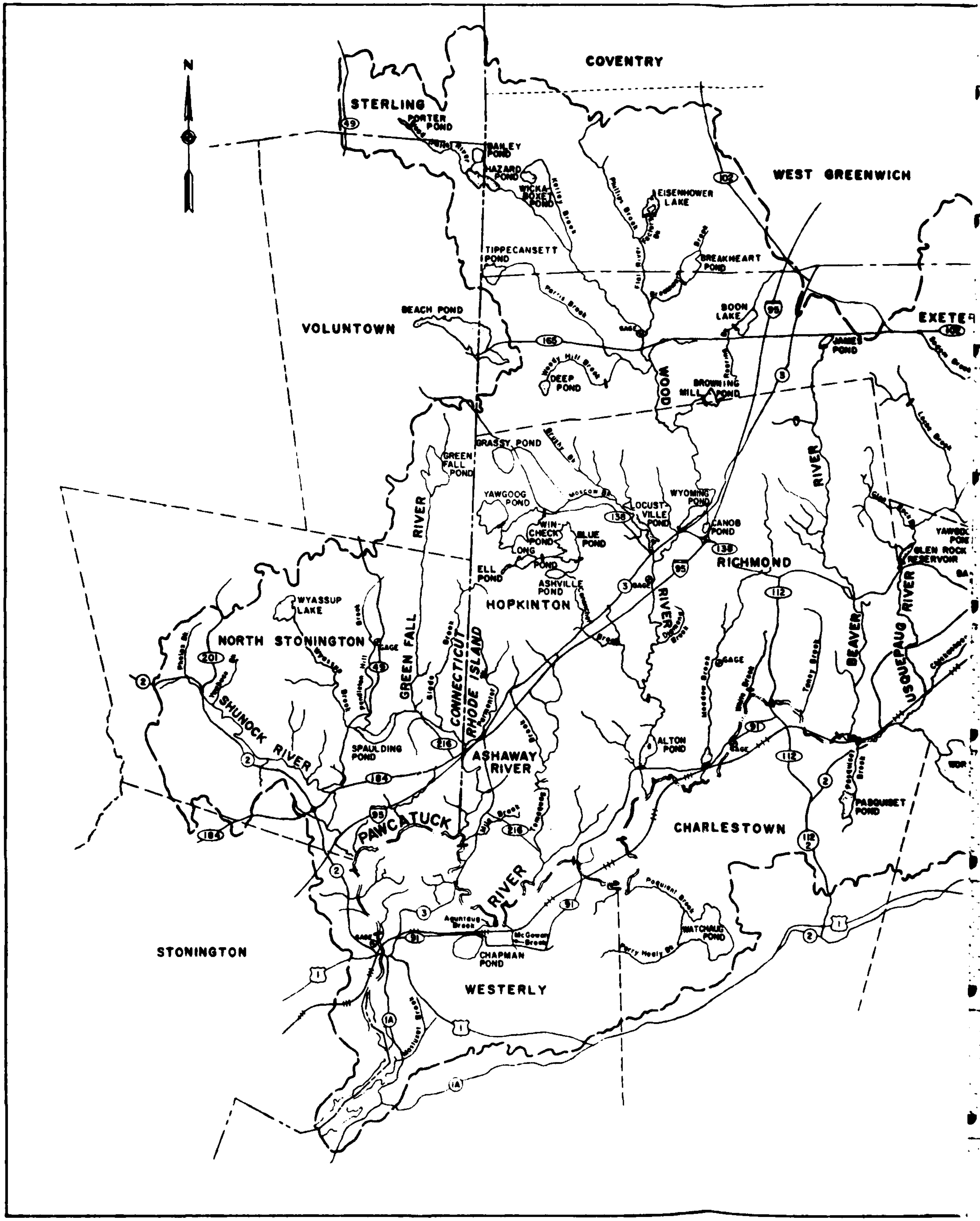
Climate

The southeastern New England region has a variable climate characterized by frequent but generally short periods of precipitation which are produced by local thunderstorms and intense "lows" of tropical and extratropical origin that move northeasterly up the coast. The area also lies in the path of the prevailing "westerlies" which generally travel across the country in an easterly or northeasterly direction producing frequent weather changes. The Narragansett Bay has a moderating effect, consequently the study areas escape the severity of cold and greater depth of snowfall experienced in the higher elevations of the interior areas of New England.

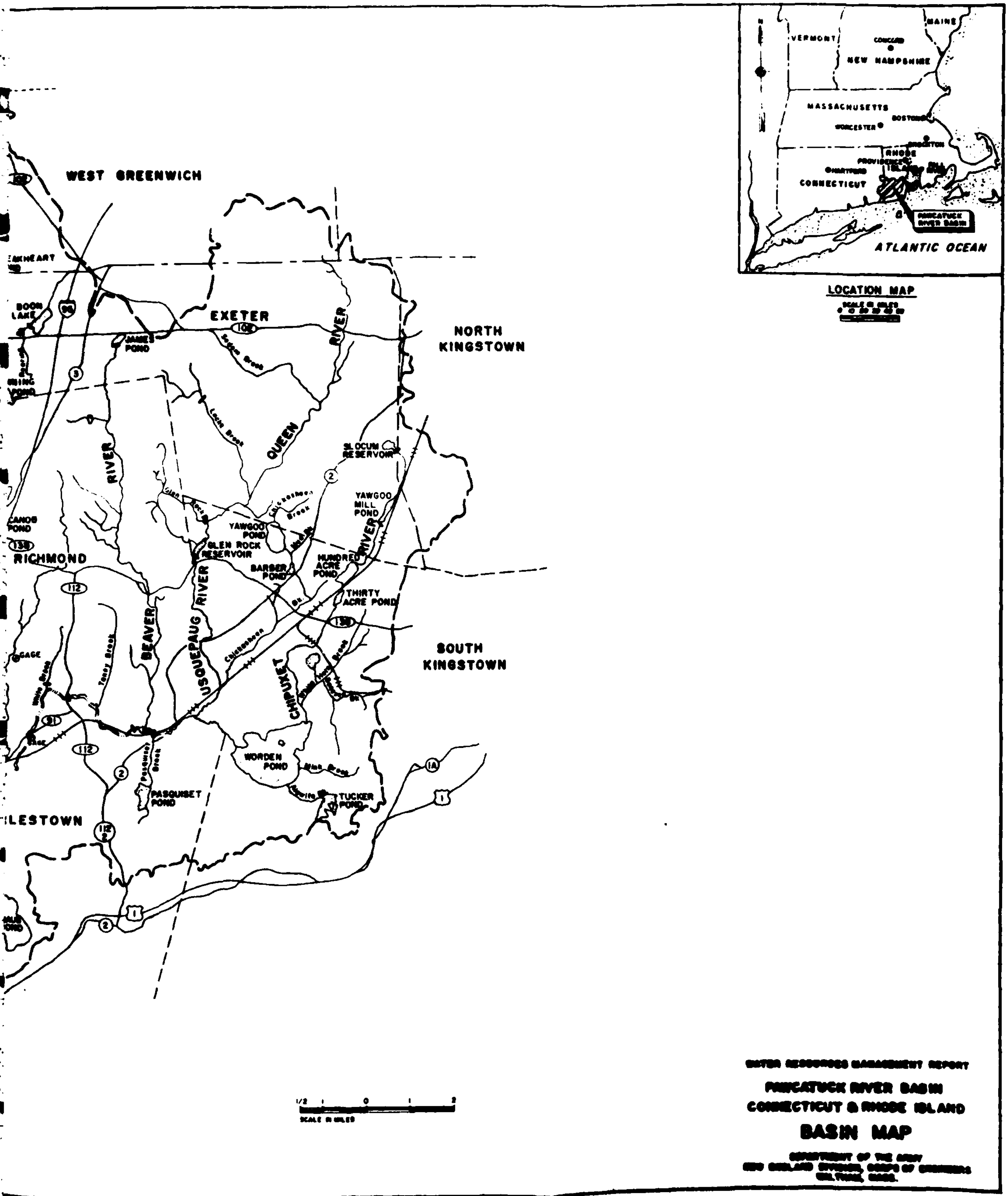
The average annual temperature within the study area is about 50°F. Mean annual precipitation varies from about 39 inches in the lower coastal area to about 48 inches in the uplands. The average annual snowfall over the Rhode Island-Connecticut region ranges from 25 to 38 inches. The frequent but short periods of heavy precipitation are caused by four general types of storms.

Topography

The study area lies in the New England Physiographic Province, which is a subdivision of the Appalachian Highlands that extend from Newfoundland to Alabama. The Woonasquatucket River Basin lies principally within the Seaboard Lowland Section. The irregular topographic surface gently slopes easterly toward Narragansett Bay from

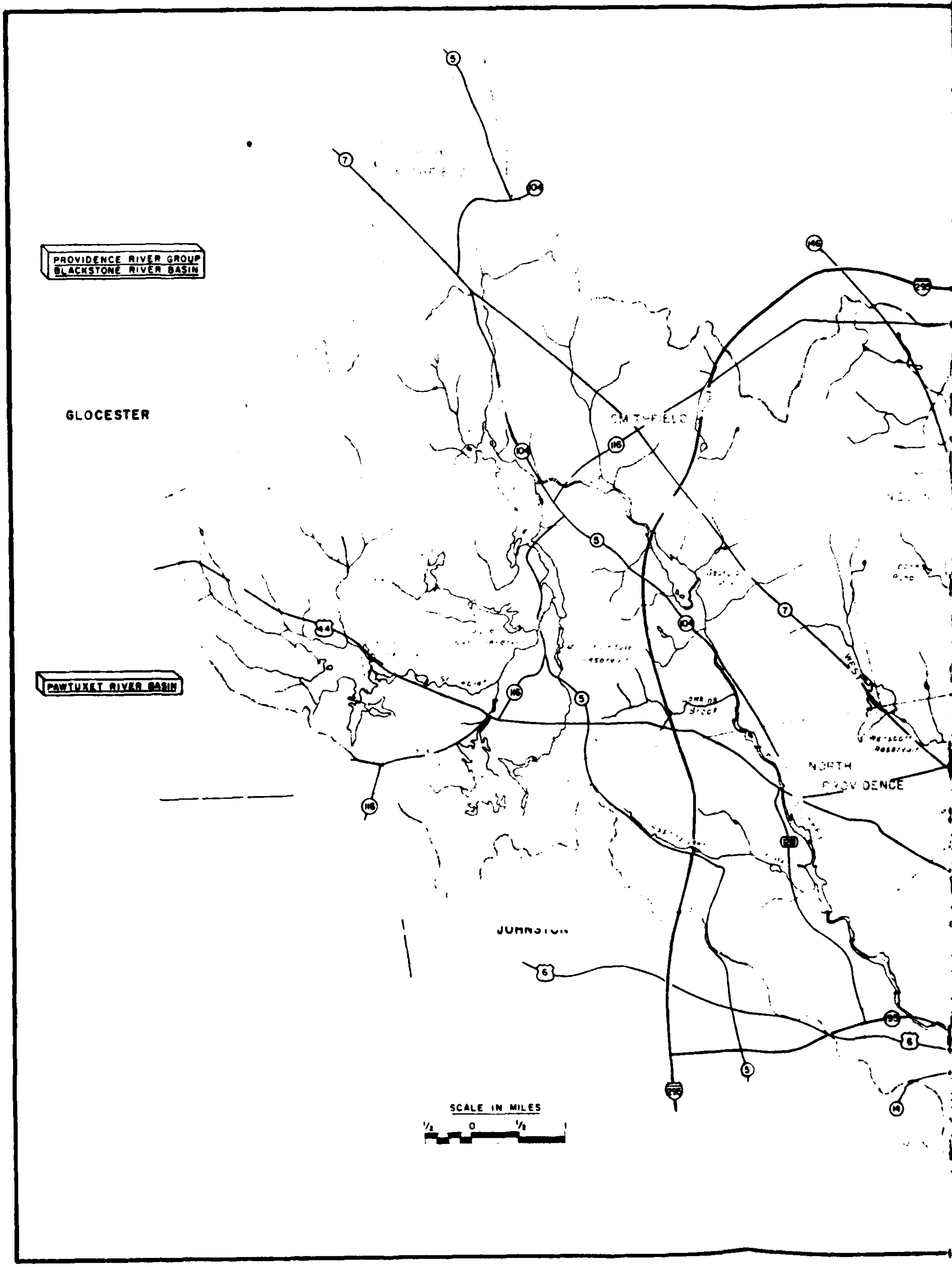


N
COVENTRY
STERLING
PORTER POND
BAILEY POND
HAZARD POND
WICKABOXET POND
WEST GREENWICH
EISENHOWER LAKE
BREAKHEART POND
TIPPECANSETT POND
BEACH POND
VOLUNTOWN
BOON LAKE
JAMES POND
DEEP POND
WOOD
BROWNING MILL POND
GRASSY POND
GREEN FALL POND
YAWGOOG POND
WYOMING POND
LOCUSTVILLE POND
CANOB POND
WINCHECK POND
BLUE POND
LONG POND
ELL POND
ASHVILLE POND
RICHMOND
GLEN ROCK RESERVOIR
HOPKINTON
WYASSUP LAKE
NORTH STONINGTON
SHUNOCK RIVER
GREEN FALL RIVER
CONNECTICUT
RHODE ISLAND
SPAULDING POND
ASHAWAY RIVER
PAWCATUCK RIVER
ALTON POND
BEAVER RIVER
USQUEPAUG RIVER
PASQUISET POND
CHARLESTOWN
WATCHAUG POND
CHAPMAN POND
STONINGTON
WESTERLY



WEST GREENWICH
EXETER
NORTH KINGSTOWN
SOUTH KINGSTOWN
RICHMOND
BOON LAKE
JAMES POND
QUEEN RIVER
SLOCUM RESERVOIR
YAWGOO MILL POND
YAWGOO POND
GLEN ROCK RESERVOIR
BARBER POND
HUNDRED ACRE POND
THIRTY ACRE POND
RIVER
BEAVER
USQUEPAUG RIVER
CHIPUXET
WORDEN POND
TUCKER POND
PASQUISET POND
LOCATION MAP
VERMONT
NEW HAMPSHIRE
MAINE
MASSACHUSETTS
BOSTON
WORCESTER
CONNECTICUT
RHODE ISLAND
PROVIDENCE
ATLANTIC OCEAN
SCALE IN MILES
PAWCATUCK RIVER BASIN
CONNECTICUT & RHODE ISLAND
BASIN MAP

PLATE 2


PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
PAWTUXET RIVER BASIN
GLOCESTER
SMITHFIELD
NORTH
PROVIDENCE
JOHNSTON
SCALE IN MILES
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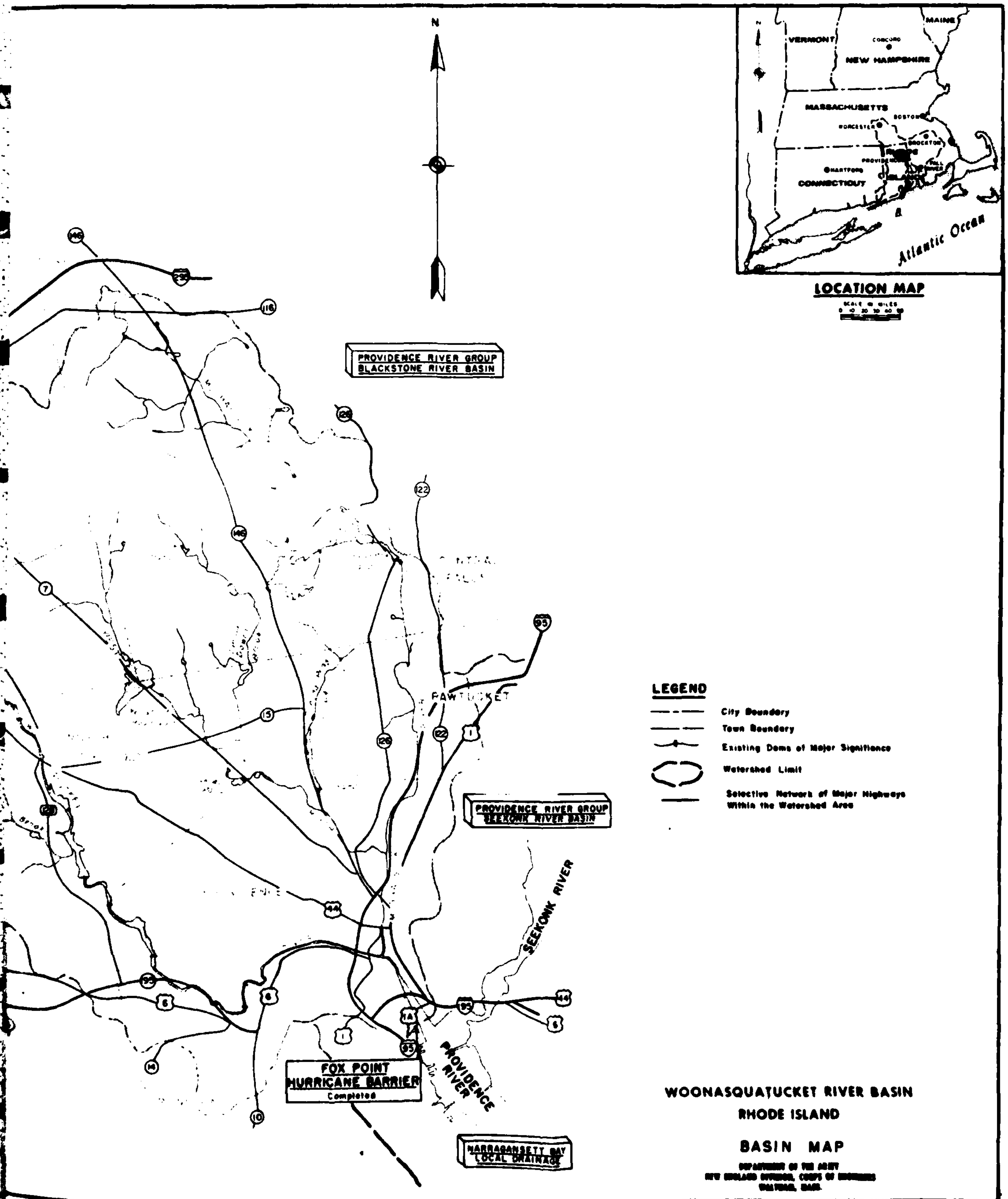
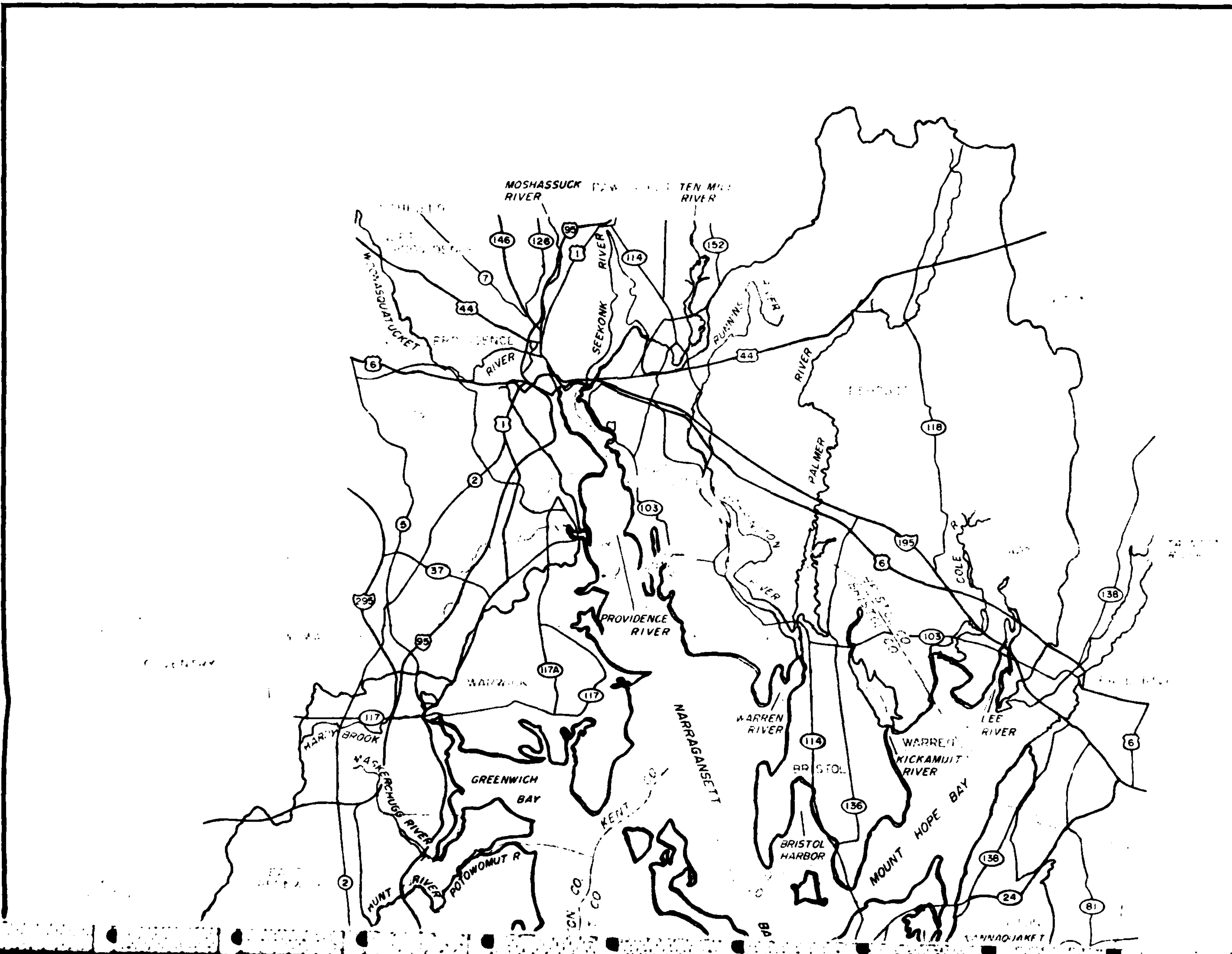


N
VERMONT
CONCORD
NEW HAMPSHIRE
MAINE
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
PROVIDENCE
HARTFORD
CONNECTICUT
Atlantic Ocean
LOCATION MAP
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
PAWTUCKET
PROVIDENCE RIVER GROUP
SEEKONK RIVER BASIN
SEEKONK RIVER
FOX POINT
HURRICANE BARRIER
Completed
PROVIDENCE RIVER
NARRAGANSETT BAY
LOCAL DRAINAGE
LEGEND
City Boundary
Town Boundary
Existing Dams of Major Significance
Watershed Limit
Selective Network of Major Highways
Within the Watershed Area
WOONASQUATUCKET RIVER BASIN
RHODE ISLAND
BASIN MAP

PLATE 3

2



MOSHASSUCK RIVER
TEN MILE RIVER
SEEKONK RIVER
PROVIDENCE RIVER
NARRAGANSETT
PALMER RIVER
COLE R
LEE RIVER
WARREN
KICKAMUIT RIVER
MOUNT HOPE BAY
BRISTOL
BRISTOL HARBOR
WARREN RIVER
GREENWICH BAY
POTOWOMUT R
HUNT RIVER
KENT
6
138
81
136
24
103
195
118
114
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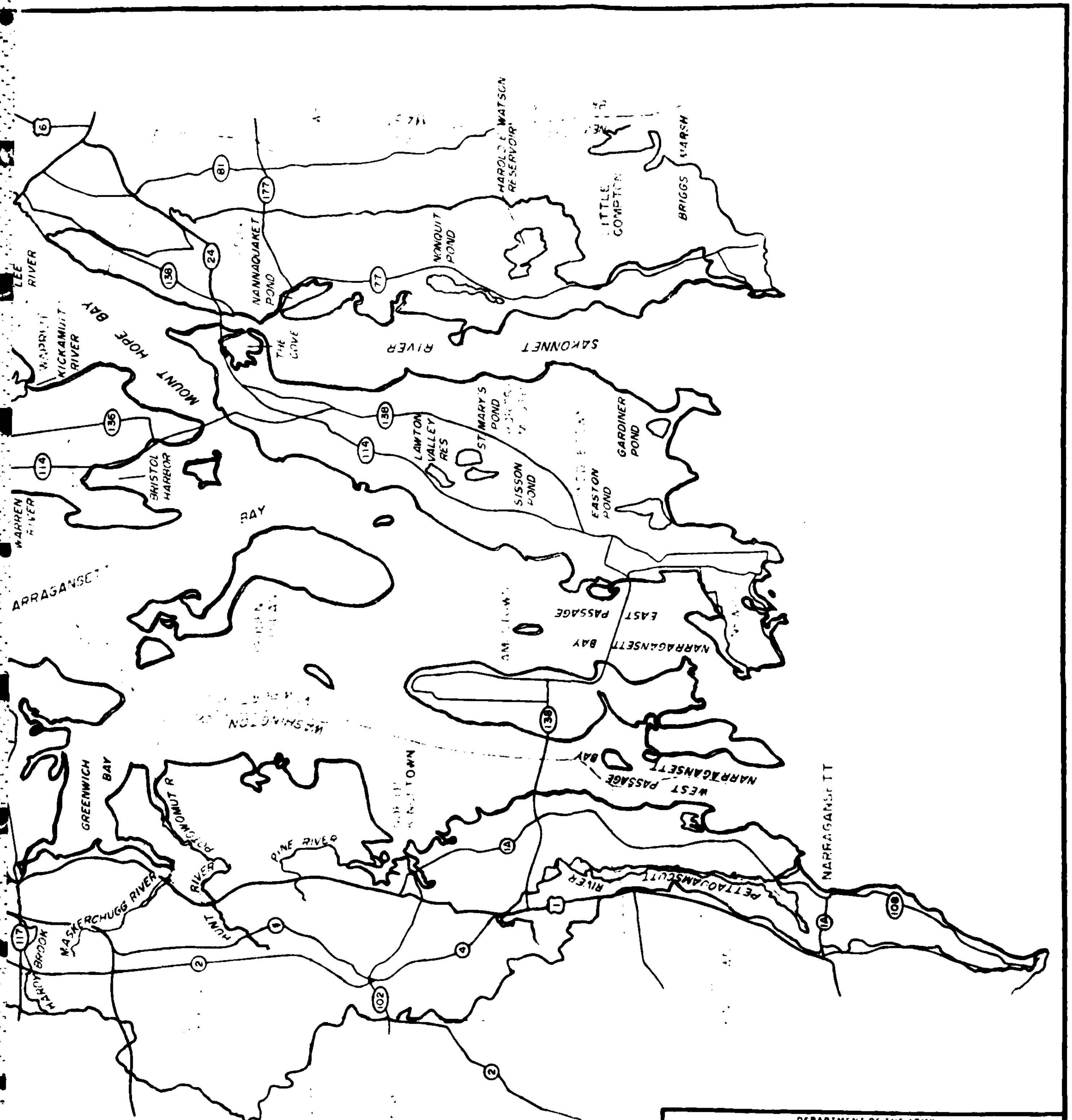


DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

NARRAGANSETT BAY
LOCAL DRAINAGE AREA
BASIN MAP

PLATE 4

2

a maximum elevation of approximately 627 National Geodetic Vertical Datum (NGVD) occurring at Absalona Hill in Gloucester. Its topography is characterized by many low hills of unconsolidated glacial materials with rock commonly providing local relief especially in the area northwest of Providence.

Much of the Pawcatuck River Basin is a lowland sloping southward from a narrow, irregular divide which is generally less than 500 feet NGVD. Low, rounded hills rise above very wide valleys where glacial deposits furnish the major relief. The surface of the whole basin has been modified by glaciation. Drainage is very poorly developed throughout the region; streams wind across the wide, flat, swampy valley flows.

Narragansett Bay and its associated coastal streams are also in the Seaboard Lowland Section.

The topography of the Narragansett Bay local drainage area is governed by geologic structure. Heavy outwash deposits from East Greenwich to Quonset provide a low flat plain at the lower elevations in the drainage area. Fluvio-glacial sands east of Nyatt Point present a slightly undulating terrace. Projections of the old sedimentary rock structure stand out as moderately high islands. The drainage area reaches a maximum elevation of about 300 feet; this occurs where crystalline old land nears the bay, notably west of Greenwich Bay.

Geology

Woonasquatucket River Basin - Woonasquatucket unconsolidated deposits mantle the bedrock surface to varying degrees throughout the Woonasquatucket-Moshassuck River Basin. The thinnest surface cover, and hence, the greatest exposure of bedrock, is evident on the sides and tops of the low hills in the central and northern sections of the basin. Surficial deposits are primarily derived from glacial action. Postglacial deposits are minor and occur as alluvium and swamp deposits near streams and blocked drainage areas on hills. Principal glacial deposits are chiefly comprised of glacial till and glaciofluvial deposits.

The basin is underlain by a nearly even proportion of igneous and metamorphic rocks with a lesser amount of sedimentary rock. Generally the metamorphic rock occurs in the western and southern sections of the basin, the igneous rock in the center area and sedimentary rock along the eastern edge and a smaller area in the southwestern section.

Sand and gravel deposits are common in the river valleys. At one time, granite, quarried from the area of Esmond and Graniteville supplied dimension stone. Presently there is limited commercial utilization of mineral resources within the basin. Limestone and marble are mined in an area northwest of Pawtucket.

Pawcatuck River Basin - The overburden throughout the basin consists of the various materials deposited as a result of glaciation. The hills are blanketed with a thin veneer of glacial till, consisting of variable, silty, gravelly sand with numerous cobbles and boulders. The greatest exposure of bedrock and the thinnest surface cover is evident on the sides and tops of low hills in the western and northern sections of the basin. A great variety of materials characteristic of glacial outwash are found in the valley. Due to glacial derangement of drainage, most of the low areas are swamps in which deposits of peat and organic materials have accumulated.

The bedrock of the Pawcatuck River Basin consists of hard, crystalline rocks, mostly Paleozoic in age. The major part of the basin is underlain by sterling granite or granite-gneiss.

Sand, gravel and stone are the only potential mineral resources in the area.

Narragansett Bay Local Drainage - The present surface and land form is largely the result of glacial erosion and deposition. The eroding of hilltops and depositing materials in valleys by glaciers changed the overall relief of the basin. Most of the surface is covered by unconsolidated glacial debris consisting of well-sorted to poorly-sorted sand, gravel and clay.

The bedrock is predominately gneiss and granite. Areas adjacent to the bay have formed shallow rock pavements with almost no sediment cover, the rough structural configuration having been complicated by extensive preglacial erosion to form gorges now under a deep cover of glacial and postglacial sediments.

Mining operations in the study area produce sand, gravel and stone which are used principally for aggregates. Many resource areas are not available for mining because of zoning, ground water involvement, or use of land for other purposes.

Seismic Activity

The study areas are located in Zone 1 of the Seismic Risk Map but are immediately adjacent to the dividing line for Zone 2. Zone 1 is classified as an area where minor damage from earthquakes can occur. Areas in Zone 2 may undergo moderate damage.

Water Supply

The Pawcatuck River Basin has abundant ground water resources and it appears that the area will be capable of supplying its own mid-to-long range needs. However, municipalities will have to establish strict land use regulations. In some cases this may involve purchasing and managing existing, privately owned water supply systems to provide better interim coordination and planning.

The principal areas within the Woonasquatucket River Basin from which ground water can be withdrawn is a blanket of stratified drift more than 60 feet thick, lying to the south of the Woonasquatucket Reservoir. A realistic sustained yield from this reservoir is 1 mgd. A second area lies in the Providence area where the projected sustained yield from this location is 4 mgd. Another area is located along the Moshassuck River Valley where ground water recharge results from direct infiltration from precipitation, subsurface inflow from till and bedrock near the aquifer, and potential infiltration from the Moshassuck River itself. Its estimated safe yield is 5.5 mgd; however, it should be noted that continual pumping and export of this amount of water from the aquifer area could cause the Moshassuck River to dry up during the summer months and in periods of drought.

The principal surface water supplier for communities within the Woonasquatucket River Basin is the Providence Water Supply Board. The entire Providence water supply is obtained from the Scituate Reservoir Complex which has a safe yield of 72 mgd, and is located in the adjoining Pawtuxet River Basin. The projected average day water supply demand on the Providence system in 1995 is 85.5 mgd, which exceeds the safe yield by 13.5 mgd. One remedy to this situation is the expansion of the Providence system by means of developing Big River Reservoir system in the Pawtuxet River Basin, and other basin transfers as indicated by the Water Resources Board of Rhode Island.

Western sections of Pawtucket and Central Falls and eastern areas of North Providence are serviced by the Pawtucket water works system. The community of Lincoln has its own water system using wells along the Blackstone River. North Smithfield, Glocester and parts of Johnston obtain their water from private wells.

Surface water supplies for the Narragansett Bay area include reservoirs supplying the communities of Bristol, Jamestown, Middletown, Newport, Portsmouth, Tiverton, Warren and Warwick. The two major water supply systems now serving the Narragansett Bay area also supply water to other basins within Rhode Island. These are the Providence Water Supply Board's Scituate Reservoir Complex and the Kent County Water Authority's wells located in Coventry and East Greenwich. Ground water resources in the bay area are irregularly distributed. The area is practically devoid of deposits favorable for the development of ground water resources capable of sustaining public water supplies. However, the bedrock aquifer in most areas is capable of yielding water to drilled wells in quantities sufficient for domestic supplies.

Water Quality

Water quality standards for classification of waters are as follows:

Class A - waters are uniformly excellent in character, suitable for domestic water supply.

Class B - suitable for domestic water supply with appropriate treatment and for swimming.

Class C - suitable for fish and wildlife habitat, boating and industrial use.

Class D - suitable for navigation, power, some industrial uses and fish migration.

Pawcatuck River - The headwaters and tributaries of the Pawcatuck River are generally Class A or B, according to Rhode Island and Connecticut water quality standards. The mainstem of the Pawcatuck is classified as B and C waters, but certain reaches are not in compliance with their classification. Those reaches not in compliance with Class B standards are: White Horn Brook, Wood River just above its confluence with the Canonchet Brook, Caroline Mill Pond on the Pawcatuck, and the Pawcatuck River between Ashaway and White Rock. All other nontidal waters in the Pawcatuck River Basin are Class C or higher. Little Narragansett Bay does not meet the standards of its SA and SB classifications due to upstream discharges. These discharges include Westerly's primary treatment plant and industrial and combined sewer discharges in Pawcatuck, Connecticut.

Woonasquatucket River - The existing water quality in the Woonasquatucket River Basin ranges from Class B to Class C. The upper portion of the basin from Waterman Reservoir to Georgiaville Pond is a series of reservoirs and old mill ponds which are predominantly Class B. Neither the Stillwater Reservoir nor the Woonasquatucket Reservoir, both located in the upper basin, are in compliance with the Class B standard due to two small wastewater treatment facilities discharging effluent just upstream of Stillwater Reservoir. They should be brought into compliance with the completion of the Smithfield sewerage system.

The lower basin from Georgiaville Pond to the Providence River is entirely Class C. The city of Providence is served by a municipal sewage system which, due to its being a combined system, is not capable of providing adequate treatment of the sewage during periods of heavy rainfall.

The Moshassuck River is Class B from its origin to Blechery Pond in Lincoln. Due to industrial and municipal discharges, the river is Class C from Blechery Pond to its confluence with the Woonasquatucket River. The Moshassuck River's major tributary, the West River is Class B.

Narragansett Bay - The upper portion of the Narragansett Bay local drainage area is intensely developed and is quite prone to problems associated with the transport of oil.

Several portions of streams within the area do not meet proposed water quality standards at this time. The Seekonk-Providence Rivers area is the most severely degraded within Narragansett Bay. The

wastewater treatment facilities in the Blackstone Valley Sewer District, East Providence, and Providence discharge significant waste into the two tidal rivers. But it is the combined sewers of Providence, Pawtucket and Central Falls which create the major water quality problems in the Providence River and upper Narragansett Bay area.

The vast majority of waters are meeting proposed standards of Class SA and SB quality waters. The Seekonk and Providence Rivers, Jamestown Harbor, portions of Mt. Hope Bay particularly around Fall River, Newport Harbor, waters surrounding the US Naval Reservation at Quonset Point, Apponaug Cove, and the Barrington River at Barrington, are all Class SC.

Fish and Wildlife

The Woonasquatucket River Basin has a moderate network of streams and ponds but due to the urban nature of this area, particularly in the lower portion of the basin, it has very few outstanding fish and wildlife habitats. Because these current habitats are insufficient and/or of low quality, it cannot support existing demands nor will it meet projected demands. Large portions of the land which support wildlife are privately owned which severely limits fish and wildlife recreation throughout the basin.

The Moshassuck and Woonasquatucket Rivers support limited aquatic life. In general the streams, ponds and impoundments of the upper portion of the basin are best suited for warm water fish; these would include smallmouth and largemouth bass, chain pickerel, white perch, yellow perch, and bullheads. Each main stem has one tributary stocked with trout.

A substantial portion of the Pawcatuck planning area is rural with 91 percent of the basin being either forest, agriculture, wetlands, or open water. The US Fish and Wildlife Service has estimated that 75 percent of the forest land is rated as fair wildlife habitat, although the state rates this wildlife habitat with higher quality. These characteristics make the basin an excellent production area for forest game species. Due to an abundance of natural water areas and wetlands it also produces significant numbers of fur animals and waterfowl.

The basin has an extensive network of streams and ponds. The Wood River is considered the best trout stream in the State of Rhode Island. Worden Pond provides the best northern pike fishing within the Pawcatuck and Narragansett Bay Study Area.

The Narragansett Bay local drainage area has an extensive network of streams and ponds. However, most of the streams are relatively small and contribute very little in the way of freshwater fishing. The open bay waters, salt ponds, freshwater areas and wetlands do, however, provide habitat for significant numbers of waterfowl. The basin's ponds and streams are relatively free of pollution and provide moderate fishing opportunities.

Harvestable fish species, considered as "cold water," include the brook, brown and rainbow trout. The principal "warm water" fish species include largemouth bass and smallmouth bass, chain pickerel, yellow perch, white perch, brown bullhead, and various sunfish. The Massachusetts Division of Fisheries and Wildlife and the Rhode Island Division of Fish and Wildlife have extensive trout stocking programs to meet the demand for stream fishing. The Palmer River in Massachusetts and the Hunt River in Rhode Island are considered to be the best trout streams in the area.

Outdoor Recreation

The Woonasquatucket River Basin has limited potential for outdoor recreation. Currently there are about 2600 acres of land (approximately 5.4 percent of the basin's total land area) devoted to recreation and conservation; this includes State and local parks, management areas, town forests, private camps and golf courses. Swimming and boating are two activities with large deficiencies due to the lack of coastline readily accessible to the basin.

There are four State parks, eight freshwater public beaches and four golf courses within the basin area. There is only one boat ramp and one private campsite.

The rural Pawcatuck River Basin is characterized by dense forests, open marshes, swamps and unspoiled streams. This is one of the most important areas in southeastern New England for swimming, boating, camping, picnicking, extensive outdoor recreation (nature study, hiking) freshwater fishing, and hunting. Almost 17 percent of the total basin land area (44,000 acres) is classified as conservation and recreation land, of which 90 percent (38,500 acres) is State owned.

The majority of the 44,000 acres of recreation and conservation land in the study area is made up of the Pachaug State Forest in Voluntown and various Rhode Island management areas. There are approximately 5,700 acres of privately owned recreation lands (camps, clubs, and campgrounds) and only 100 acres of locally owned conservation and recreation lands. According to the Bureau of Outdoor Recreation, these resources will more than satisfy the future demands of area residents for hiking, nature study, and photography, and a large portion of their demands for camping.

Narragansett Bay, Rhode Island's greatest natural resource, is a focal point for population growth, recreation, commerce, and fisheries. The bay has many islands; the two largest, Aquidneck and Conanicut, are much more heavily developed than Prudence Island which, unlike the others, has no highway access. These three large islands and many smaller ones, and the numerous coves and estuaries, make the bay a haven for recreational boating, swimming, saltwater fishing, camping, picnicking, extensive outdoor recreation, and wildlife and fisheries production. These activities play important roles in the bay area's

recreational scene. The bay's historical and natural resources presently contribute significantly to satisfying some outdoor recreation demands, and to enhancing the Providence area's quality of life.

HUMAN RESOURCES

The population densities in the study area communities range from 36 inhabitants per square mile in West Greenwich to 14,397 inhabitants per square mile in Central Falls. Excluding Providence which decreased by 69,000 between 1950 and 1970, population in the other communities increased from 543,222 in 1950 to 777,600 in 1970, representing a 43 percent increase. With the exception of the older communities of Central Falls, Pawtucket, and Providence, which lost population, the communities in the study area have experienced a steady population growth.

In 1970, 7.8 percent of the State's residents were foreign born and 25 percent had foreign or mixed parentage. Roughly one-third of the ethnic backgrounds were Italian or Canadian. British, Irish, Portugese, Polish and Russian accounted for another third, with all other origins accounting for the remainder. Rhode Island has one of the lowest educational attainment levels in the nation. In 1970, less than half the population 25 years of age or older had completed high school and only 5.2 percent had completed four or more years of college. This has restricted many residents to low paying jobs.

DEVELOPMENT AND ECONOMY

Early Development

Prior to the arrival of European settlers, Rhode Island was inhabited by five Indian tribes of Algonquin stock. The first European settlement was established in 1636 by Roger Williams, who fled the Massachusetts Bay Colony and purchased the northern half of what is now Rhode Island from the Narragansett tribe. Settlements within other portions of the study area soon followed.

During the early development years, the scattered villages were principally agricultural communities. Early industries included gristmills and sawmills at a few waterpower sites, and an iron foundry in Scituate. Limited mining of bog iron ore, soapstone, and granite took place and a small fishing industry developed. The seaport of Providence served the waterborne commerce needs of the basin, as it does today.

In the early 1800's, numerous waterpower sites were developed for the manufacturing of textiles particularly along the Woonasquatucket River. Jewelry and silverware industries developed about this time with the subsequent development of the fabricated metal industries.

Later Development and Urbanization

The Industrial Revolution saw many major groups of mills established near available waterpower sites. Each group became an independent community. Each set of mills was worked by a distinct ethnic group, and British workers were first displaced by Irish, then French-Canadian, Polish, Italian, and most recently Portugese. These strong, local communities precluded the growth of "downtown" central business districts, except in Providence.

From the Civil War through World War I, the area continued to prosper and its industrial base grew. During the 1920's, however, textile mills began to move south and communities began to decline. There was relatively little growth or migration during the depression of the 1930's.

The turning point in the economy came in the early 1940's, when mills were converted to war work and new industries developed, such as electronics, precision instruments, and plastic and synthetic fibers. Many new jobs were created at naval installations at North Kingstown and Newport. And the extension of the public transit system from Providence into adjacent communities, along with the growth of automobile transportation created new suburban development.

Between 1950 and 1970, Providence lost significant population, while most other Rhode Island communities grew, some very rapidly. Many new residents were attracted by the desirability of suburban living close to Narragansett Bay. Migration was assisted by the availability of a good highway system.

Despite this growth, Rhode Island as a whole has generally experienced higher unemployment rates than the rest of the nation. Since World War II, there has been only one boom period (1965-70), but four major recessions. During the present recessionary period, Rhode Island's unemployment rate has remained roughly twice the national average.

Rhode Island has been a marginal producer, quick to feel the effects of economic downturn and slow to reap the rewards of prosperity. Lack of public services has also restricted the growth of industry.

Textiles, jewelry, and silverware continue to be major industries, with Providence still providing the preponderance of jobs for area residents. In the other basin communities, trade, diversified manufacturing, government, and service industries represent the major employment classification. The loss of 20,000 military personnel and 10,000 civilian jobs through the phaseout of the state's two major naval installations has created severe economic hardship, although this should be partially offset by the utilization of one former naval installation at North Kingstown for the construction of nuclear submarines.

Urban sprawl and commercial strip development have characterized much of the growth radiating out from the earlier mill villages. New industrial growth has tended to cluster along service roads or railroads, and more recently in industrial parks.

Transportation

Providence is a key wholesale distribution center in the heart of the New England market. The basin is well served by all types of transportation.

Major highways include I-95 connecting Boston, Providence, and New York; I-295, the outer belt highway around Providence; I-195, connecting Providence, Fall River and New Bedford; US-1, following the coastline from Providence to Westerly; US-6 and US-44. An extensive state highway system serves the entire state.

Railroad Service - both bulk freight and passenger, connects Providence with Boston, Worcester and New York.

Air Passenger and Air Freight - needs are handled at the state-operated T. F. Green Airport in Warwick and at several small airports throughout the state.

Waterborne Commerce - is served by the Port of Providence, which has a 40-foot-deep main channel and 21 terminals.

Land Use

Between 1960 and 1970, urban land use increased sharply, largely at the expense of agricultural lands. Roughly 25 percent of the agricultural lands were lost to urbanization. This shift from agricultural to urban uses during the 60's reflects the large increase in population during that period.

More than half the land in the study area is forested. The majority of the remaining land is utilized for agricultural and residential uses.

CONDITION IF NO FEDERAL ACTION TAKEN

The condition most likely to occur in the basin without any Federal action will be continued growth. With the advent of the Flood Insurance Program the trend of unwise development of the intermediate flood plan should be reduced, but not eliminated. Development will continue to occur in the land area between the 100-year flood and the Standard Project Flood (SPF). Losses can therefore be expected to increase although not in the same proportion as prior to the initiation of the Flood Insurance Program and flood plain zoning.

As urbanization continues, the runoff rate will increase, causing higher flood peaks than previously experienced. Development that is now flood free at a 100-year flood could get damaged at a 50-year event due to this increase in urban area. If the zoning is not adhered to and the flood plain is filled along with upstream retention areas, the situation will worsen and even greater increases in flood stages can be anticipated. More frequent flooding can be expected with a larger area subject to inundation.

PROBLEMS, NEEDS AND OPPORTUNITIES

Pawcatuck River Basin

Although the Pawcatuck planning area has experienced several relatively rare flood events, the damage associated with these floods has been minimal in the nontidal portion of the basin. The tidal portion is now protected by the Pawcatuck Local Protection Project. Flat terrain, numerous ponds and streams, extensive wetlands and minimum development have combined to limit the extent of inland flooding in the Pawcatuck area. The flood of record occurred in March 1968. Other major floods were in February 1886, November 1927 and September 1932.

Numerous ponds and an extensive network of wetland areas plus a significant amount of undeveloped forested land have served to modify high floodflows and keep flood damages at minimal levels. A total of some 3,700 acres of lakes and ponds are scattered throughout the area. Nearly one half of the total water surface area is concentrated in the southerly sections or downstream areas of the basin. The largest is Worden Pond in South Kingstown where the Pawcatuck River originates; the second in size is Watchaug Pond in Charlestown. During flooding periods these ponds and lakes act as detention areas where excess runoff is stored thus reducing the amount of floodwaters entering the extreme downstream.

In addition to these open water bodies, many wetland areas are scattered throughout the basin and they also provide additional natural valley storage areas where excess runoff can be temporarily stored prior to release into downstream areas. Inland wetland areas total over 30,000 acres or about 47 square miles. This consititutes over 15 percent of the total land area in the Pawcatuck River Basin. The largest individual wetland area in the basin is the Great Swamp located within the Great Swamp Wildlife Reservation in South Kingstown.

Flood plain wetlands are especially valuable due to their dual function as both flood plains and wetlands. During flood condition, these wetlands act as both natural storage areas and as an increased channel area to pass flows. Due to this enlargement, the velocity and hence rate of flow is slowed down and result in a reduced flood stage downstream. The loss of these wetlands would usually cause greater damage than the loss of an equivalent wetland area in the upper reaches of a drainage area.

Along the Pawcatuck River there are several areas which have experienced some minor flood damages. These areas are located in the communities of Westerly, Carolina, Richmond, and White Rock, Rhode Island and Pawcatuck, Connecticut. Hope Valley and Alton on the Wood River, and the confluence of the Pawcatuck River and Tomaquag Brook in Rhode Island have also experienced some flooding.

In Hope Valley the problem is downstream of Locustville Pond where the Route 3 bridge opening does not appear to be adequate to pass heavy flows. This would result in a buildup of floodwaters causing flows to go over the road. As the village below is fairly low several businesses and the local fire station could be inundated.

In addition, there are a few potential flood damage areas along the tributaries of the Pawcatuck. The first of these is the village of Ashaway (in Hopkinton, Rhode Island) which has been built across the flood plain of the Ashaway River about three-fourths of a mile above the confluence with the Pawcatuck River. A manufacturing company and several residential buildings are subject to flooding in this area. Estimates for damages to this area from the occurrence of a 100-year storm would amount to about $150,000. A second potential damage area is that of the village of North Stonington, Connecticut, where a small group of homes have located within the 100-year flood plain of the Shunock River. A potential problem could exist at a new residential area just downstream of the center of Westerly. The homes have been built at the existing ground levels some of which are quite susceptible to inundation by either extreme tides or storm surges. However, the developer has built an earth dike protecting the area. The dike's top width is less than 5 feet and varies in elevation with a maximum height of less than 10 feet. No provisions for a pumping station or adequate control of interior drainage was evident. The dike could provide a false sense of security to the residents living behind it especially if maintenance and upkeep are not performed periodically.

Hurricane and severe storm tidal flooding along the Rhode Island coast, in Little Narragansett Bay and vicinity, has been recorded since 1635. Historical data regarding maximum tidal elevations is very sparse. A flood frequency relationship has been approximated using highwater mark elevation data, historical records for hurricanes and severe storms, and the records of the US Geological Survey gage, located on the Pawcatuck River at Westerly, Rhode Island.

The Groton-Stonington-Pawcatuck area has been subjected to tidal flooding from three major hurricanes; severe flooding from those of September 1938 and August 1954 (Carol), and moderate flooding from the hurricane of September 1944.

In the past, riverine flooding has not caused extensive damage in the nontidal portion of the Pawcatuck River Basin. This cannot be construed, however, to mean that damage will never occur. As developmental pressure continues to increase throughout the area, more

wetland areas could be lost. This loss of wetlands will increase the potential for flood damages in areas that were not previously flood prone.

Normally, the rate at which runoff enters the river or stream increases as the amount of development increases. Rainfall in builtup areas, rather than permeating into the ground, will result in virtually instantaneous runoff and will quickly enter the river or stream.

Economic projections indicate that there will be a population increase of about 58 percent in Rhode Island by 1990. Proper planning can allow economic growth to continue while limiting the detrimental effect of that development. By carefully controlling development in the area, it is possible to allow for an economic or environmental future and still maintain the environmental integrity of the area.

The Pawcatuck area has abundant ground water resources and is expected to be able to supply its own mid to long term water needs. Currently proposed municipal wastewater treatment plant construction in Westerly, Stonington, Pawcatuck, and Hope Valley should help upgrade the water quality in problem areas. Generally high quality water is expected to be maintained throughout the Pawcatuck basin.

Public and privately owned recreation and conservation is abundant in the Pawcatuck area, however, public access to many waterfront recreation areas is often limited. According to the US Heritage, Conservation and Recreation Service (HCRS) these resources will more than satisfy the 1990 demands of area residents for hiking, nature study, and photography, and a large portion of their demands for camping. About 22,400 acres are publicly owned and open to hunting; and another 66,000 acres are privately owned and open to hunting. However, due to the close proximity of the Pawcatuck Basin to the Providence metropolitan area, much of the hunting demands of that city will be diverted to this area.

Woonasquatucket River Basin

Flooding in the basin can occur at any time of the year. Historical flooding has been reported to dates in the early 1800's. Since that time numerous flood producing storms have been experienced. As mentioned earlier the area is adjacent to the Providence metropolitan area in close proximity to the seacoast, and well serviced by the highway systems. Hence the lower and middle portions of the basin have become captive to the demands imposed by urbanization.

Urbanization may significantly change the watershed's response to precipitation which can result in substantially higher peak rates of runoff. The degree of change depends upon several factors: the amount of new paving or rooftop; the addition of local drainage conveyances; and the loss of natural valley storage areas. If a large residential development is placed in a formerly wooded area, the overall changes in

runoff rates would probably be minor. The towns zoning laws establish the minimum lot size. Hence, assuming a 12,000 square foot building lot, the amount of impervious area added is relatively minor. A typical new home, a raised ranch with garage under, is generally 44′ x 26′ or 1,144 square feet. A typical driveway would be 40 ′ x 10′ or an additional 4,400 square feet, for a total impervious area of about 1,550 square feet, or an increase of about 13 percent. For a minor rainfall, the runoff from the newly developed area would be greater, as the area now has a greater impervious percentage. This would yield a slightly higher flow, but would not create a flooding condition unless severely undersized culverts are in the waterway system. As the rainfall event increases in both intensity and duration, the impervious factor decreases in importance. This is due to the creation of "excess rainfall." The rainfall eventually gets to an intensity/duration where the natural soil may no longer absorb it. At this point in time, it also acts as impervious area and most, if not all, of the future rainfall is conveyed to the nearest waterway. This latter condition is what creates virtually all of the riverine flooding conditions. Snowpack and frozen ground conditions can add to the flood problems.

Industrial-commercial development is different in the problems it may create to the downstream areas. Obviously, major industrial-commercial complexes are much larger. Virtually the entire land area is impervious, approaching 90 to 100 percent impervious in some instances. All rainfall is immediate runoff. The additional problem created by such complexes is that the runoff is now increased in velocity as the friction factors are significantly lower. Water runs off of asphalt much faster than over a saturated forest area. This corresponds to a greater water depth that can be anticipated, unless storage basins are created in the industrial-commercial complex.

Filling in of wetlands results in less storage available in the area to hold flood runoff. If the filled area is significant, or placed in a restrictive portion of the natural stream channel, higher flood heights both upstream and downstream are possible. Key areas such as the floodway are usually identified on flood insurance rate maps if the municipality participates in the regular program of the National Flood Insurance Program.

Although considerable portions of the lower basin are already approaching a completely urbanized appearance, development is occurring in the middle and upper basin. The municipalities should ensure that the developer take into consideration the potential flooding effects. Wise development should not pose any increase in flooding conditions.

Along the mainstem of the Woonasquatucket, flooding can be directly associated with poor channel maintenance, flood plain encroachment, inadequate channel capacity and inadequately sized bridge openings.

The Moshassuck River begins in Lincoln and flows 7.2 miles southerly to its confluence with the Woonasquatucket River in

Providence. The upper portion of the basin is rural and in the past has not had many reported instances of damages due to riverine flooding. Moderate losses have been experienced in the lower two thirds of the basin. Average annual losses on the Moshassuck River are $80,500. However, most of the industrial-commercial establishments have been built out of the areas normally inundated by moderate flood events.

The West River, a tributary of the Moshassuck, has a very significant flood problem. The river originates along the border of the towns of Lincoln and Smithfield. It flows for a distance of 6.8 miles to its confluence with the Moshassuck. Development in the West River subbasin has been much more rapid than in the Moshassuck. In the upper portion development has been of a residential nature with a few scattered commercial centers while the lower portion of the West River has been developed for industry and manufacturing. In order to provide for this growth, swamps or lowlands were filled in, and streams channelized. Some of the channels have even been filled in further reducing the flow carrying capacities of the stream. In several instances, dams were breached on old ponds and the lands reclaimed to be built upon. These trends coupled with the increased runoff characteristics of the basin contribute to the nearly annual flooding the area receives. In the West-Moshassuck Basin recurring losses associated with the 100-year flood are estimated at $12,852,000 at 1981 price levels. Average annual losses on the West River are $924,000.

The flood history of the basin demonstrates that major floods can occur any season of the year as a result of intense rainfall alone or in combination with snowmelt. The magnitude of freshwater flooding on the Woonasquatucket River is a function of a storm rainfall and the resultant runoff from the 36.9 square miles of drainage downstream of the large impoundments mentioned above, as well as the magnitude and timing of the discharges of the initial storage capacity in these impoundments.

The basin's towns contain a relatively meager amount of land available for recreational use. Roughly equal portions of 2,600 acres of recreational land is owned by the state, municipalities and private interests. This constitutes approximately 5.8 percent of the watershed's total land area. The Woonasquatucket and its banks are principally developed for industrial, commercial and residential use and infrequently used for outdoor recreation. In addition, the river is severely polluted at the present time. Consequently, the lands immediately adjacent to the Woonasquatucket River have limited potential for recreational development. The Moshassuck River presents a similar situation. The HCRS estimates that by 1990 only 14 percent of the demand for freshwater beaches, 20 percent of the demand for picnic facilities and 25 percent of the demand for accessible natural areas will be met. As tourism in the Providence metropolitan area increases and development within the basin continues, this demand will be inflated further.

Although there are a modest number of freshwater ponds within the basin, availability for fish and wildlife recreation is limited. Unfortunately, pollution has greatly reduced the quality of many ponds and streams making them insufficient to support substantial fish life,

if any. In addition, of those areas of acceptable water quality, private ownership of adjacent lands blocks access to many of them. Hunting facilities are faced with similar deficiencies.

A substantial portion of the Woonasquatucket-Moshassuck River is urbanized, approximately 33 percent as estimated by the US Department of Agriculture, Soil Conservation Service in March 1975. With the exception of Providence, the communities of the basin experienced a rapid population growth rate of 22.3 percent between 1950 and 1970. This increase consumed much land previously available for natural resources. As considerable future growth is projected, it must be guided to developable lands to insure the critical remaining environmental resources are protected.

The Providence Water Supply Board provides three of the four principal basin communities with water--Providence, North Providence and Smithfield. The fourth community, Lincoln, has its own water system using wells along the Blackstone River. In 1970, the basin had a population of 232,000 and they consumed 37 million gallons per day (mgd). By 1990 projections indicate an increase in population to about 245,000 requiring 47 mgd. By 2020, approximately 60 mgd will be needed to supply almost 300,000 people.

In addition to the basin area population growth, the projections show that future demands for public water supply are growing at a steady pace and shall continue in the future.

The basin lies within a zone where precipitation is well distributed throughout the year. Extended periods of dryness have been recorded, however, which frequently affect streamflow and surface and ground water supplies. Prior to 1936 rainfall data is sparse. Since the establishment of gaging stations, significant droughts have occurred between 1941 and 1944, 1948 and 1950 and 1963 and 1966. This latter period is the most severe on record and had a significant impact on the water resources of the region. Ground water provides the primary source of streamflow between periods of rainfall. Ground water storage is generally replenished during each spring runoff and rarely is a deficiency of this source carried over from one year to the next.

Narragansett Bay Local Drainage Area

Inland flooding damages in the Narragansett Bay local drainage area have been minimal. The flat topography and relatively broad flood plains of the surrounding area adequately modify floodflows, thereby reducing flood stages. The abundance of wetlands, which provide significant natural valley storage, and the low development density of the flood plain also help lessen flood damage costs. Loss of these existing natural valley storage areas and increased development in the flood plains could result in more frequent and serious flooding in the Narragansett Bay area.

The greatest concentration of damages due to hurricanes usually occurs within the city of Providence. The east bank of the Providence River has experienced heavy industrial damages. Losses occurring in the Providence Harbor area due to the hurricanes of 1938 and 1954 have included a yacht club, docks, boatyards, tanks and oil refineries. Heavy damages could occur from Fields Point north to the Fox Point Barrier.

Along the Cranston shoreline, boats and yacht clubs have been demolished by hurricanes. Another heavily damaged area, the Warwick Industrial Park, is located along the tidal reach of the Pawtuxet River. This area has been thoroughly covered in the Pawtuxet River Interim Report. Also in Warwick, in the Shawomet and Oakland Beach sections, many homes and cottages were leveled during the 1938 hurricane. Oakland Beach and Buttonwoods, both heavily developed residential areas, are directly in the path of any storm coming into Narragansett Bay. In the event of a storm of the magnitude of the 1938 hurricane, Apponaug Cove and surrounding areas would experience high industrial losses. Heavy residential damages to about 90 cottages and year-round homes would result at Sandy Point on Potowomet Neck, and also similar losses would occur at Buttonwoods and Warwick Cove.

In North Kingstown, losses due to the 1954 hurricane included extensive damage to facilities at the US Naval Reserve Quonset Naval Air Station and the Naval Construction Battalion Center at Davisville; however, both have been almost completely closed down at this time. Also numerous homes and commercial establishments in the area suffered considerable damages. Flooding could also affect homes located in Shore Acres, a relatively low, flat point that extends into Wickford Harbor.

Destruction on the Narragansett waterfront has been serious due to past hurricanes, particularly along the Narragansett Pier. The East Shore Ferry Station in Jamestown Harbor has been badly damaged during past hurricanes and many cottages on East Shore Drive have been totally destroyed. Virtually all have been rebuilt at the same approximate elevations.

East Providence has experienced industrial and commercial losses mainly in the vicinity of the Wilkes-Barre Pier and Bold Point. Bullock Point, also in East Providence, has experienced heavy residential losses to year-round homes. This is also true of the Allen Neck section of West Barrington and Rumstick Neck and Adams Point in Barrington. The Warren River, particularly along the low, flat eastern shoreline, is subject to tidal flooding causing considerable industrial and commercial damages. Several manufacturing firms have sustained severe tidal flooding in past hurricanes.

Heavy waterfront losses in Bristol Harbor have included boatyards, docks and harbor facilities, and summer homes and cottages. Overflow of the tidal reach of the Taunton River has been substantial, affecting the towns of Dighton, Somerset, Berkeley, Freetown, Swansea, Taunton and Fall River, Massachusetts. South Swansea is flooded by both the Mt. Hope Bay and the tidal reach of the Lees River. The southern and northwestern shorelines of Aquidneck Island have been heavily battered

by hurricane tides of Narragansett Bay and the Sakonnet River. Newport Harbor, Island Park in Portsmouth and the long, exposed, southern shoreline at Newport Neck have sustained heavy damages in the past. In the vicinity of Long Wharf, flooding occurred as much as 2,000 feet inland in 1954, flooding numerous houses, stores and warehouses. Recreational and commercial boats were destroyed and beaches and cottages along the southern shoreline were severely damaged. Because of the excellent harbor facilities, it has long been one of the principal ports on the Atlantic coast. There are numerous shops and restaurants along the Newport Harbor waterfront. These are in a low, flat area and many are located on the piers, all susceptible to heavy damages. A recently built hotel and restaurant complex on Goat Island in Newport Harbor could also suffer substantial damages.

There are four types of damages resulting from hurricanes: saltwater flooding due to the hurricane surge, riverine flooding from heavy rains, storm driven waves, and high velocity winds. A long period of heavy precipitation followed by the torrential rains accompanying a hurricane has often generated numerous flash floods.

Investigations by the USGS show that the mean sea level along the New England coast has been rising at a rate of approximately 0.02 foot per year since 1930. In the event of a recurrence of a storm of the magnitude of the 1938 or 1954 hurricanes, flood levels nearly 1 foot higher would now occur. The severity of future hurricane tidal flooding will be continually increasing due to this change in mean sea level. There are currently eight recording tide gages in operation in and around Narragansett Bay. The locations of these gages are Old Saybrook, New London, Groton and Stonington, Connecticut; Mondale, New York, Westerly, Narragansett and Block Island, Rhode Island.

A number of hurricanes and cyclonic storms have reached the coast of southern New England with devastating force while numerous other storms have passed so close that a slight change in meteorologic conditions could have resulted in severe damage. Rhode Island lies in the path of hurricanes moving into New England from the south and therefore has frequently been subjected to tidal floodings from hurricane surges.

The possibility also exists in the lower reaches of the streams that both riverine and tidal flooding could occur simultaneously producing higher stages than either could individually. For this situation to occur it would be necessary for the tidal surge to occur at approximately the same time as the peak runoff and the astronomical high tide. Also the greatest rainfall is at the center of the hurricane whereas the highest wind velocities occur to the right of the center due to the counterclockwise spiral movement. For a large runoff to occur in the lower reaches at the time of the tidal surge there would have to be a considerable amount of rainfall immediately prior to the hurricane.

Projections indicate a population growth of 32 percent between 1970 and 1990. If recent trends continue, agricultural land uses will

decrease as urban uses increase. Without careful planning, the loss of wetlands and flood plains will aggravate flooding and storm damage problems, water supply, plant and wildlife habitat and erosion.

Currently available water supply sources will be inadequate to meet 1990 demands. It is currently anticipated that the Providence Water Supply Board will have to extend service to four additional municipalities in the bay area. The proposed Big River Reservoir is expected to be a major additional source of supply by 1995. High quality waters in the Narragansett Bay area will be imperiled as growth continues. High water quality prevails in many portions of the bay; preservation of existing water quality to higher standards must be pursued. Currently, almost 75 percent of the area's population use septic systems for wastewater disposal. This situation may change with the occurrence of new growth and development which can be channeled towards proposed sewer service areas in order to make the most efficient use of utilities available.

Narragansett Bay, Rhode Island's greatest natural resource, is a haven for outdoor recreation, and fish and wildlife, but existing recreation facilities will not be able to meet the growing recreational demands from this and surrounding areas. Existing beach area will be able to meet about a third of the area's future needs; existing campsites could meet about a third of the total 1990 demand for camping and the existing publicly accessible parks and natural areas will meet more than a third of the demands for extensive outdoor recreation. Tourism and recreational demands from the nearby Providence metropolitan area inflate this demand further. Recreation resources of Narragansett Bay will increasingly be pressured by the rapidly growing population within this and adjacent areas.

PLANNING CONSTRAINTS

- Any channel improvements cannot worsen conditions upstream or downstream without provisions for mitigation.

- For benefit calculation purposes, all new growth must adhere to the provisions of the National Flood Insurance Program as required by law.

PLANNING OBJECTIVES

- Reduce existing flood losses in the Pawcatuck and Woonasquatucket River Basins and the Narragansett Bay local drainage area.

- Minimize impacts to existing natural resources.

- Alert flood plain inhabitants and the general public to the dangers of flooding in the study area.

- Minimize the potential for future additional losses to presently undeveloped lands.

- Coordinate flood control measures with water supply, water quality, recreation and fish and wildlife needs in the area, and in particular with Rhode Island's Statewide Comprehensive Outdoor Recreation Plan (see Appendix 5).

CHAPTER THREE: FORMULATION OF PRELIMINARY PLANS

TABLES

FIGURES

FORMULATION OF PRELIMINARY PLANS

FORMULATION OF PRELIMINARY PLANS

Principal water resource problems within the basin show the need for flood management measures, phased development of public water supplies and water quality improvement measures. Alternative solutions for satisfying flood control needs are evaluated in this section. Water supply and water quality improvement measures have been the subject of previous and ongoing studies by the Rhode Island Water Resources Board, Rhode Island Statewide Planning Program, and this office.

MANAGEMENT MEASURES

All potential regulatory and corrective measures for meeting the flood protection needs of the basin were initially identified and briefly appraised. Implausible measures were rejected. A No Action Plan (one entailing no Corps of Engineers participation) was considered throughout the plan formulation process. It assumes that all communities will control growth within their flood plains, at least to meet the minimum requirements of the ongoing National Flood Insurance Program (NFIP). The NFIP provides a Federal subsidy to private insurers so that flood prone properties may be eligible for flood insurance ($90,000 limit for single family residence and contents, and $400,000 limit for non-residential property and contents).

Presently most basin communities have initiated participation in the NFIP which should lead to local programs for controlling growth within the flood plains. Communities declining to participate become ineligible for any Federal expenditures within a flood prone development, and property owners for properties within the flood plains would be unable to obtain financing from federally insured lending institutions.

Regulatory measures discourage the use and development of the flood plains, thus lessening the threat of flood damage and possible loss of life.

Flood plain regulations help avoid repetition of past building errors by preventing additional construction on already developed flood plains. Communities may adopt more stringent regulations than those required by the NFIP. Such restrictions require the enactment of ordinances to implement and enforce land use planning programs involving the delineation of flood hazard areas.

Encroachment lines drawn on the map on each side of a watercourse show the lateral limits within which development must be restricted in order to preserve the flood carrying capacity of the stream and prevent further growth in the flood plain. Figure 1 is a schematic drawing of this concept. The central portion, or floodway, consists of the stream channel and that portion of the adjoining flood plain required to pass a

100-year flood. No construction or filling should be allowed there, although parking lots, recreation, agriculture, and other nonstructural uses may be permitted, provided that the free flowing state of the floodway is not impaired.

The floodway fringe is the remainder of the 100-year flood plain. Limited encroachment or filling may be allowed here, providing it does not cause the water level of the 100-year flood to rise more than one foot (or less if so established by state or local regulations). Any construction here must be floodproofed to the 100-year flood level.

Zoning is the legal measure used to enforce land use and development restrictions in the flood plain by governmental agencies. It insures the safekeeping of this property for the health, welfare, and safety of the public.

Subdivision regulations are used by local governments to control construction in undeveloped flood plains by specifying minimum elevations, drainage, location restrictions, and other conditions to prohibit encroachment in flood hazard areas.

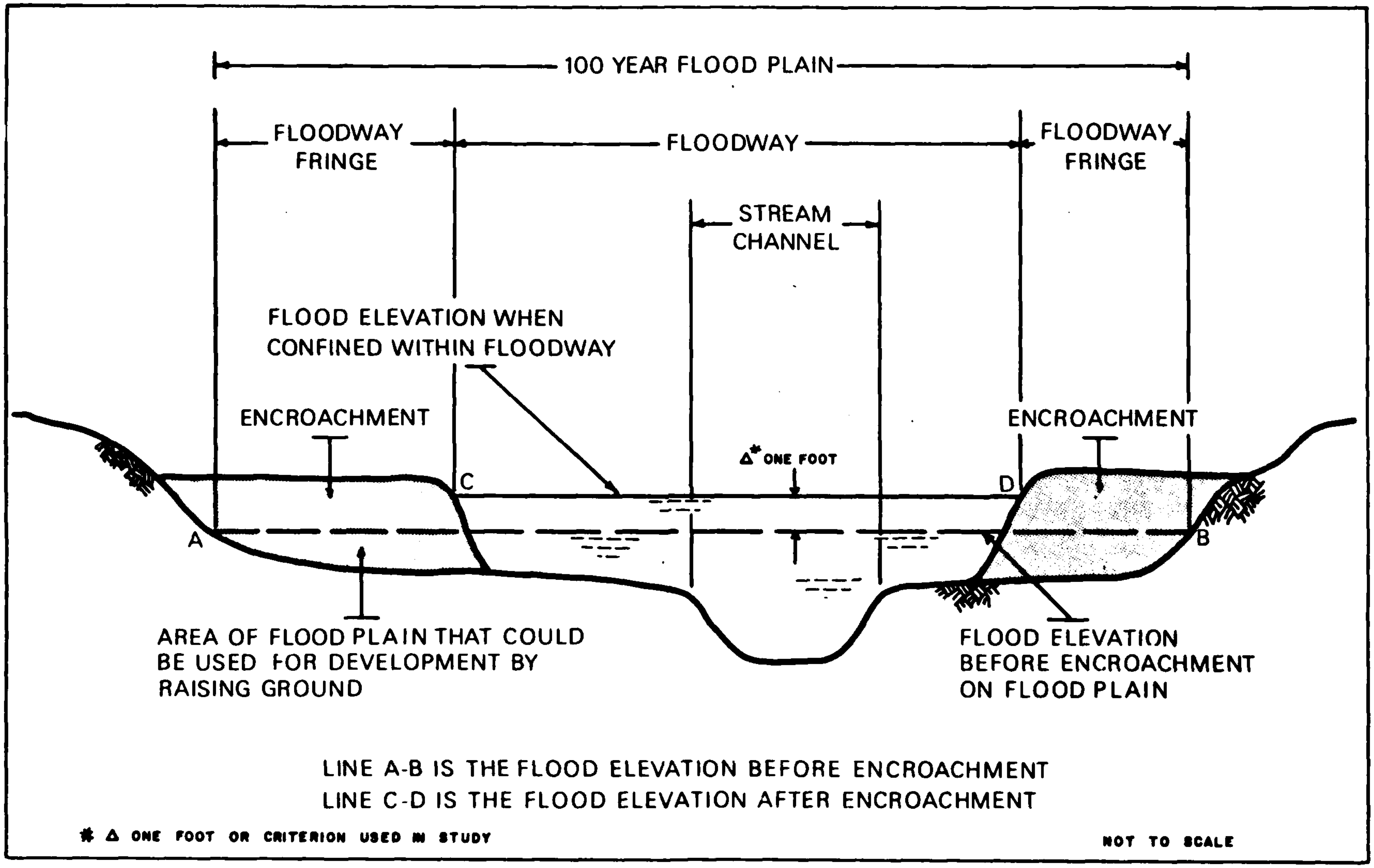
Land use programs for conservation, scenic, and flood control purposes may include land use restrictions, purchase of land use rights, lowering of tax assessments, and other measures to meet public objectives—such as preventing development in flood plains--while allowing continued private ownership of the land.

Other regulatory measures to lessen the threat of flood losses include the following:

- Building codes which specify minimum standards of design, construction, and quality of materials to reduce potential flood damages in structures whose location in flood hazard areas cannot be prevented. Such restrictions could prevent buildings from floating off their foundations, establish minimum basement and first floor elevations consistent with potential flood occurrrences, prohibit basements that would be subject to shallow flooding, require reinforcement to withstand water pressure or high velocity flow, restrict the use of materials which deteriorate rapidly in the presence of water, and prohibit equipment that might be hazardous to life when submerged.

- Urban redevelopment presents opportunities to remove developments from the flood plain and make sure that new construction in the flood plain is designed to withstand flooding.

- Tax adjustments on land dedicated to open space uses, such as agriculture, recreation, and conservation, helps to preserve undeveloped flood plains.



DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
Federal Insurance Administration

FLOODWAY SCHEMATIC

FIGURE 1

- Warning signs of previous high water levels warn prospective buyers that a flood hazard exists. Required certification by sellers that the property is reasonably flood free is even more effective.

- Health and fire regulations should include contingency plans for temporary evacuation of people, property, and livestock from low-lying areas, prevention of disease should water supplies become polluted or sanitation facilities inoperative, accessibility to fire fighting equipment, and emergency fire reporting systems.

- Flood forecasting can reduce property losses significantly and save lives. Information from the Federal government's extensive weather forecasting system should be effectively disseminated at the local level.

- Land treatment measures reduce erosion, reduce runoff, and lessen the damaging movement of sediments to streams and flood plains. Vegetative and mechanical measures developed for conservation practices—contour farming, cover cropping, terracing, critical area planting, and the like—are also effective on urban lands undergoing development.

- Reservoir management programs provide for the addition of flood control storage in existing reservoirs, with controlled release after the flood danger passes.

- Stream improvements can increase the flood carrying capacity of floodways by eliminating abrupt turns, widening and deepening channels, improving areas at bridges and culverts, alleviating erosion problems, and removing shoals, sandbars, islands, overhanging and uprooted trees, and accumulated debris. Diversion of floodflows to bypass heavily congested flood prone areas offer great protection while minimizing environmental and social impacts.

- Floodproofing or relocation measures render buildings and contents less vulnerable to flood damage. They include:

  1. Permanent measures such as waterproofing, installation of drain systems and pumps, anchoring and reinforcing walls and floors, use of water resistant materials, raising the elevation of structures, terminating entering utilities, protecting immovable equipment, bricking windows, relocating entrances, and drawing up plans for emergency protection measures.

  2. Contingency measures such as manually closed sewer valves and removable bulkheads for windows, doors and vents.

  3. Emergency measures such as sandbagging, pumping and removal of contents to high elevations.

4. Permanent evacuation of developed areas by removing structures and relocating people, so that flood prone lands could be returned to natural habitat or used for agriculture, parks and recreation. Temporary evacuation is also effective when used in conjunction with a reliable flood warning system.

STRUCTURAL MEASURES

- Structural components are often the most practical way to control floods and reduce damage in heavily urbanized flood prone areas where regulatory measures would be too expensive or environmentally or socially undesirable.

- Reservoirs for impounding uncontrolled floodwaters provide a high level of protection to downstream communities, while satisfying other needs, such as water supply and public recreation.

- Walls and dikes confine floodflows to the channel or floodway and provide protection to local high-risk areas.

- Hurricane barriers use walls, dikes, gates, and pumping facilities to prevent high tides from intruding and raising flood heights along the lower main stem.

PLAN FORMULATION RATIONALE

In evaluating possible alternative solutions for the basin's flood management needs, technical, economic and social criteria (see Appendix 2), including consideration of all beneficial and detrimental effects on the area's environment, were used. Although it was not possible to evaluate all possible alternatives to the same degree of technical detail, supplemental planning criteria for all possible alternatives involved acceptability, completeness, effectiveness, equity, irreversible effects, and ease of maintenance and operation. Socioeconomic data used in evaluating costs and benefits were derived from Corps investigations and other published data of state and Federal agencies. Hydrologic and hydraulic data were obtained from Corps studies. Environmental impact information was obtained from Corps studies and water quality sampling by the US Environmental Protection Agency.

ANALYSIS OF PLANS CONSIDERED IN PRELIMINARY PLANNING

Initial Screening

All regulatory and corrective measures, as well as a No Action plan, were evaluated with engineering judgment and brief study for applicability in each of the three watersheds. Each measure was judged on its own merits and those not considered adequate, realistic, practical engineering solutions, or measures socially or environmentally unacceptable or economically unjustified were eliminated. The No Action plan and all regulatory measures were determined to be applicable throughout the study area, for preventing or minimizing flood losses to future flood plain development. Both programs were therefore retained for further evaluation.

Land treatment measures are not applicable in any of the three watersheds as they do not have any significant erosion and sedimentation problems at this time.

Several reservoir sites were investigated in the Woonasquatucket and Pawcatuck River basins however all were too small and too far from damage centers to afford any significant degree of protection.

Numerous local protection projects were considered throughout the entire study area. In the Woonasquatucket River Basin the high risk flood prone areas where walls and dikes would be effective in providing flood protection were located in 2 damage zones. Walls and dikes were eliminated from further consideration in all other zones. A local protection project for Westerly, Rhode Island near the mouth of the Pawcatuck River would not be economically justified based on the costs of the similar existing Pawcatuck Local Protection Project in Stonington, Connecticut on the opposite shore. The Pawcatuck Local Protection Project provides protection to an industrial area having the potential for higher losses than the residential/commercial area in Westerly. Seven local protection projects were proposed in the Narragansett Bay coastal area. Although initial reports indicated that some of the projects may be justified, all lacked local support.

The reservoir management program was eliminated after it was deemed economically infeasible, socially unacceptable, and impractical from an engineering standpoint as the existing reservoirs would not provide sufficient storage and their modification costs for rehabilitation or raising would far exceed the benefits to be derived.

A hurricane survey report for the Narragansett Bay area was prepared by the Corps of Engineers in 1965. The recommended plan consisted of three barriers in the entrance to the bay, the east and west passages and the Sakonnet River. Due to a lack of support from Rhode Island cities and towns further investigation was terminated.

Most stream improvement possibilites proved to be infeasible from an engineering or economic standpoint. However, further investigations involving channel modification in 2 damage zones of the Woonasquatucket River Basin were warranted.

Some floodproofing measures might prove to be economically justified for single structure establishments or residences. Relocation may warrant further evaluation by individuals where one or two isolated structures suffer frequent heavy damages.

Intermediate Screening

This phase of the plan formulation efforts combined the single action measures that were considered feasible from the initial screening. Additional analyses were conducted on each alternative in this stage. Alternatives involved various combinations and design

levels. One of the alternatives consisted of the No Action plan. All alternatives assumed that flood insurance would be available for the various communities within the watershed. This would help eliminate future flood losses to new development. The remainder of the planning process dealt with the derivation of detailed costs, benefits, and evaluation of various flood control systems.

The major components of the three alternative plans for the Woonasquatucket River are described in the following paragraphs. preliminary cost estimates are included in Appendix 4.

Alternative A - This alternative would provide protection to the SPF level along the Woonasquatucket River in the Olneyville section of Providence. It would consist of:

- Removal of 3 dams (Paragon, Rising Sun, and Bulkhead Dams),
- Replacement of 1 dam (Bulkhead Dam),
- Removal of 11 Bridges,
- Replacement of 8 of the bridges removed,
- 6,900 feet of concrete "U" shaped channel from Bulkhead Dam to Acorn Street,
- Removal of 4 buildings,
- Replacement of 2 of the buildings removed,
- 700 feet of concrete transition channel,
- Removal of 900 feet of masonry walls,
- Earth support system and underpinning,
- Box conduit,
- Diversion weir,
- Concrete rectangular channel section,
- Pumping station,
- Trapezoidal channel with stone slope protection from Acorn Street to Crawford Square.

The cost of Alternative A is $53.5 million (1977 Price Level).

Alternative B - This alternative would provide protection to the 300-year event level along the Woonasquatucket River in Olneyville. It would consist of:

- Removal of 3 dams (Paragon, Rising Sun, and Bulkhead Dam),
- Replacement of Bulkhead Dam
- Removal of 10 bridges,
- Replacement of 6 bridges,
- Removal of 2 buildings,
- Removal of 900 feet of masonry walls,
- Earth support system and underpinning,
- Concrete "U" shaped channel (8,270 feet),
- Concrete rectangular channel section,
- Box conduit,
- Diversion weir,
- Trapezoidal channel with stone slope protection (6,360 feet).

The cost of Alternative B is $32.1 million (1977 Price Level).

Alternative C - This alternative would provide protection to the 100-year event level along the Woonasquatucket River in Olneyville. It would consist of:

- Removal of 3 dams (Paragon, Rising Sun, and Bulkhead Dam),
- Replacement of 1 dam (Bulkhead Dam),
- Removal of 10 bridges,
- Replacement of 6 bridges,
- Removal of 2 buildings,
- Replacement of 2 buildings,
- Removal of 900 feet of masonry walls,
- Earth support system and underpinning,
- Concrete "U" shaped channel,

- Concrete rectangular channel section,

- Box conduit,

- Diversion weir,

- Trapezoidal channel with stone slope protection.

The protection scheme of Alternative C is identical to Alternative B but with reduced channel sizes. The cost of Alternative C is $28.7 million (1977 Price Level).

Along the West and Moshassuck Rivers, minor channel modifications--clearing and deepening--were considered, however, it was determined that the reduction in flooding would be relatively minor and substantial residual losses would result from the 100-year flood. A major modification scheme was investigated in detail. Table 1 is the Summary Comparison. This project involved clearing and deepening the channel, and reconstruction of several bridges, a bascule gate, a weir and two conduits.

The estimated cost (see Appendix 4) is $24,309,000 and average annual charges are $2,067,400. Benefits (see Appendix 2) are approximately $924,000. The resulting benefit-to-cost ratio is 0.49 to 1.00.

Another flood control project considered on the West River was a ringwall that would surround the industrial/commercial complex at 387 Charles Street. This would not reduce flood elevations but would prevent water from entering the complex and provide protection to either a 100-year flood or SPF level depending upon the height of the walls. However, not only would a ring wall keep water out, it would also keep water in the industrial complex. The cost of the ring wall combined with the cost of providing interior drainage and pumps to expel the water from inside the area eliminates this plan from consideration.

TABLE
SUMMARY COMPARISON

	Base Condition	No
A. Plan Description	Significant flooding along West and Moshassuck Rivers in Providence particularly at 2 industrial/ commercial complexes.	No Federal flood cont pliance with the Nati ance Program Zoning i
B. Impact Assessment		
NED Objective:	a.) Losses would continue and because of urbanization will result in higher annual damages. b.) Property values of flood prone structures will not appreciate.	a.)Losses would conti b.)Participation in N Insurance Program (NF
EQ Objective:	a.) Flooding contributes to water quality degradation. b.) Floodplain encroachment in many areas reduces amount and variety of natural vegetation and wildlife. c.) Flooding contributes to diminishing aesthetic values of basin.	a.) NFIP will help mi development in floodp
SWB Account:	a.) Perpetual threat of flooding. b.) Low real estate values in flood prone areas. c.) Possible health hazards due to flooding.	a.) Flood threat rem b.) Real Estate trans plain property would c.) Reduced property
RD Account:	a.) Flooding often causes businesses to close for several days or more. b.) Under-utilization of available ind./com. floor space due to threat of inundation. c.) Unemployment rate consistently lower than the national average.	a.) Continued flood t in relocation of floo b.) Decrease in the a cient use of com./ind
C. Plan Evaluation		
1. Contributions to Planning Objectives:	NA	Limits the extent of through regulatory me
2. Net Affects	NA	Increase in existing increased flood stage urbanization.
3. Plan Response to Associated Evaluation Criteria:	NA	
Acceptability		Yes
Completeness		No, this plan wou'd h by local authority.
Effectiveness & Efficiency		Only to the degree of regulatory measures.
Certainty		Moderate
Geographic Scope		Entirely w/in Basin.
Reversibility		Yes
Stability		Moderate
4. Rankings of Plans	NA	
NED		NA
EQ		1
SWB		2
RD		2
D. Implementation Responsibilities (Present Legislation)	NA	NA

TABLE
SUMMARY COMPARISON

Base Condition	No Action	Plan A
Significant flooding along West and Moshassuck Rivers in Providence particularly at 2 industrial/commercial complexes.	No Federal flood control project. Compliance with the National Flood Insurance Program Zoning is assumed.	Major channel modification including diversion conduit.
a.) Losses would continue and because of urbanization will result in higher annual damages. b.) Property values of flood prone structures will not appreciate.	a.)Losses would continue b.)Participation in National Flood Insurance Program (NFIP).	Project Benefits $924,000 Annual Charges $2,067,400 B/C Ratio 0.49 to 1
a.) Flooding contributes to water quality degradation. b.) Floodplain encroachment in many areas reduces amount and variety of natural vegetation and wildlife. c.) Flooding contributes to diminishing aesthetic values of basin.	a.) NFIP will help minimize development in floodplain.	a.) Reduction in damages. b.) Channel improvements will help increase the aesthetic value of the river.
a.) Perpetual threat of flooding. b.) Low real estate values in flood prone areas. c.) Possible health hazards due to flooding.	a.) Flood threat remains. b.) Real Estate transactions of flood plain property would be more difficult. c.) Reduced property values.	Increased sense of security.
a.) Flooding often causes businesses to close for several days or more. b.) Under-utilization of available ind./com. floor space due to threat of inundation. c.) Unemployment rate consistently lower than the national average.	a.) Continued flood threat may result in relocation of flood prone industries. b.) Decrease in the amount and inefficient use of com./ind. floor space.	Better use of industrial/commercial areas possible at both Branch Ave. and Charles St.
NA	Limits the extent of future damages through regulatory measures.	Reduction in existing flood losses.
NA	Increase in existing losses due to increased flood stages resulting from urbanization.	Provides a high degree of flood protection and reduce flood stages.
NA		
	Yes	
	No, this plan would be implemented by local authority.	Bridge modifications would be done by local authority.
	Only to the degree of enforcement of regulatory measures.	Most effective & efficient for entire flood prone area.
	Moderate	Low
	Entirely w/in Basin.	Entirely w/in Basin
	Yes	No
	Moderate	Moderate
NA		
	NA	-
	1	2
	2	1
	2	1
NA	NA	

2

CHAPTER FOUR: CONCLUSIONS

CONCLUSIONS

All of the structural measures investigated for Federal implementation in the Woonasquatucket and Pawcatuck River basins and the Narragansett Bay local drainage area proved to be economically unjustified, impractical or socially unacceptable. The only measures that can be recommended are the nonstructural or regulatory types. The major wetland areas many of which are already protected, particularly along the Pawcatuck River, should be preserved by enforcement of the State of Rhode Island Fresh Water Wetlands Act of 1971, the State of Connecticut Inland Wetlands and Water Courses Act of 1972 and the 404 Permit Program of the Corps of Engineers. This can help assure that increased flood problems in downstream reaches will not occur as long as new development is kept out of the flood plains.

The second and equally important flood management recommendation is the adoption at the community level of appropriate and equitable flood plain zoning. The Federal Flood Insurance Program under Flood Insurance and Hazard Mitigation office of the Federal Emergency Management Administration (FEMA) as presently administered serves as a strong stimulus for the adoption of flood plain zoning. This program also provides assistance through the delineation of flood prone areas. Only the latter of the two recommendations is applicable to the tidal communities. For these communities it is most imperative that they prohibit new growth in the flood prone areas.

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